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A STUDY OF PCB DESTRUCTION EFFICIENCY AND PERFORMANCE FOR A COAL FIRED UTILITY BOILER

VOLUME 2: TEST PROTOCOL

by

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16. ABSTRACT The report gives results of an evaluation of the adequacy of a large coal-fired utility boiler for disposal of oils containing 50-499 ppm of PCBs under conditions set by the PCB Disposal Regulations. TVA's Widows Creek Boiler No. 1 was used for the tests. In these tests, all effluent streams were sampled and analyzed, to determine representative values of Destruction Efficiency (DE) for this technology. The average PCB content of the oil used was 215 ppm. Test results indicated that, at the maximum contaminated oil feed rate of 454 L/min (120 gal./hr) utilized, boiler efficiency was not discernibly affected. Further, analyses showed that PCB levels were below laboratory-established detection limits. On the basis that both the flue gases and the fly ash could have contained PCB concentrations just below the quantifiable level, the minimum (worst case) DE can be determined. The average over six tests (two from each of three feed configurations) showed a DE of 99.95% which, since the actual concentrations of PCBs were probably significantly below the detection limits, appears to represent a minimum value for the DE in the system. Test results showed that the technology represented by Widows Creek Boiler No. 1 meets the stated requirements of a 99.9% DE for destruction of PCBs in waste oil in the 50-499 ppm range.

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NOTICE

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FOREWORD

There are several features of the Widow's Creek installation which made this facility less than perfectly suited for the experiments described herein. On the other hand, available information suggests that the physical arrangements of the Widow's Creek facility are similar to those of many other power generating utility boilers. Thus, it would seem that, in spite of the problems introducted by uncertainties in determining such parameters as the rate of production of fly and/or bottom ash, these problems are likely to be common to all such installations. This becomes significant when it is recognized that a considerable portion of the stocks of contaminated waste oil will be disposed of in such boilers, after the proposed experiments have been successfully carried out.

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SECTION 1

INTRODUCTION

As a result of the actions of the Environmental Protection Agency (EPA) in banning the manufacture of PCBs and in requiring that PCBs and PCB contaminated material still in service be withdrawn as soon as is practical, there is a large and growing reservoir of PCB-contaminated hydrocarbons in the United States. These materials derive from such sources as transformers and the washings from transformers as the PCB contents are phased out and from heat exchange systems as the contents are replaced. In any case, many of these contaminated materials possess significant energy content and therefore could serve as fuel for some industrial processes. In this era of very high fuel costs, there is great demand for PCB-contaminated materials to be used as fuel. A further impetus in this direction is the fact that the PCB Disposal Regulations (referred to herein as the Regulations) specify[1] that incineration is the preferred method of disposal of PCBs and of PCB-contaminated materials.

The Regulations carefully specify the minimal thermal conditions that must be obtained for the safe incineration of PCBs and PCB-contaminated materials. The Regulations were written this way because, at present, no suitable on-stream instrumentation exists that would allow the continuous monitoring of the effluent concentrations of such compounds as the PCBs, especially at the very low allowable emission levels. Only by specifying rigorous thermal conditions can it be assured that there will be no significant PCB emissions from an incinerator. The minimal conditions that have been specified were derived from extrapolations from several reported PCB incineration experiments.

It is further stipulated that PCB-contaminated materials are to be considered as three separate classes of materials depending on the level of PCB contamination. Those materials containing more than 500 ppm PCB can only be disposed of in an incinerator that has been specifically tested for its ability

to meet the thermal conditions specified in the Regulations. Those materials containing below 50 ppm PCBs may be treated as ordinary fuel mixtures and used for a variety of thermal purposes. The remaining class of materials, those with PCB concentrations between 50 and 500 ppm, may be used as fuels in high efficiency boilers after it has been established that such use results in a PCB destruction efficiency of not less than 99.9%.[1]

It is possible that the thermal conditions existing within a typical high efficiency power boiler would not meet the specific conditions of the Regulations. The fact that the combustion gases from a coal fired system are known[2] to contain significant concentrations of polycyclic aromatic hydrocarbons (PAHs), coupled with the reported conversion of PCBs into the corresponding chlorinated dibenzofurans (PCDFs)[3] at temperatures of approximately 700 to 800°C, suggests the possibility of the formation of important concentrations of toxic intermediates when PCB-contaminated oils are co-fired with coal.

To illustrate the problem of the generation and possible release of such oxygen-containing compounds as the polychlorinated dibenzofurans (PCDFs) and the polychlorinated dibenzodioxins (PCDDs), we refer to the work of Hutzinger and coworkers[4] who examined the fly ash from a number of incinerators in the Netherlands and found both classes of compounds present in nearly all samples. This fact was further confirmed by Buser and coworkers[5] who reported similar findings with municipal incinerators in Switzerland. A similar study by Eiceman et al.,[6] who examined fly ash samples from Canada, Japan, and the Netherlands, showed the presence of over one hundred identifiable organic compounds with the sum of the tetrachloro dibenzo-p-dioxins (total) at an estimated concentration of 2 to 10 ng/g. A very recent summary of the problem as it appears in municipal incinerators has been presented by Hutzinger et al.[4] with the following conclusions:

"a. In all cases examined PCDD, PCDF as well as several chlorobenzenes have been found in concentrations ranging from ppb up to 1 ppm.

b. In most cases the concentration of PCDD and PCDF collected in the fly ash from the precipitator is significantly lower than that collected from the particulate matter in the stack."

This latter observation (b) is consistent with PCDDs and PCDFs being present at the surface of the particles rather than within the interior. Since the fines represent larger surface to volume ratios than the precipitator-collected ash, the concentration would appear higher in the fines.

These conclusions are particularly relevant to the proposed incineration study when the results reported by Buser et al.[3] are considered; they found significant concentrations of PCDFs formed during the incineration of PCBs. There is the additional possibility that the reported formation of polychlorinated hydroxy biphenyls[7] could cyclize to form PCDDs, but this process, or rather its possible result, has not been observed. In view of these considerations, it is highly desirable that a series of co-firing experiments be carried out on a coal-fired high efficiency power boiler. Such a test series is described in this document.

SECTION 2

WIDOW'S CREEK POWER BOILERS

The TVA facility at Widow's Creek consists of eight power boilers and the necessary facilities for their operation. Of greatest interest in the context of the proposed experiments is the bank of six boilers, numbers 1 through 6. Boiler Number 1 is representative of the set and is the specific unit on which the proposed studies would be carried out. The general specifications of the unit are listed in Table 1.

TABLE 1. GENERAL SPECIFICATIONS OF UNIT 1 AT WIDOW'S CREEK

Nominal Power Rating	125 megawatts (1250×10^6 Btu/hr)
Steam Generated	4.54×10^5 kg/hr (1×10^6 lbs/hr)
Coal Input	5.08×10^4 kg/hr (56 tons/hr) @ capacity
Air Input	$3.6\text{-}4.5 \times 10^5$ kg/hr ($0.8 - 1.0 \times 10^6$ lb/hr)
APC Equipment	Cascaded Electrostatic Precipitators (four)
Stack Height	304.8 m (1000 ft); serves all six units

Fuel, in the form of pulverized coal, is fed through sixteen nozzles driven by compressed and preheated air. These nozzles are divided into two banks of eight, located on the A and B faces, respectively, of the boiler. There are also sixteen oil feed startup nozzles simiarily divided (not all of these nozzles are used during the startup). The interior configuration of the boiler is such that all the side walls are covered with boiler tubes. In addition, there is a double set of tubes running through the center, in the vertical plane, which effectively serve to separate the two sides of the boiler into the designated A and B sides.

The combustion gases, A and B streams, each pass through preheaters, economizers and thence into a set of four electrostatic precipitators (ESP) in cascade. The emergent gases from the ESPs are then conducted into the plenum of the stack which serves all six of the boilers.

SAMPLING CONDITIONS AND LOCATIONS

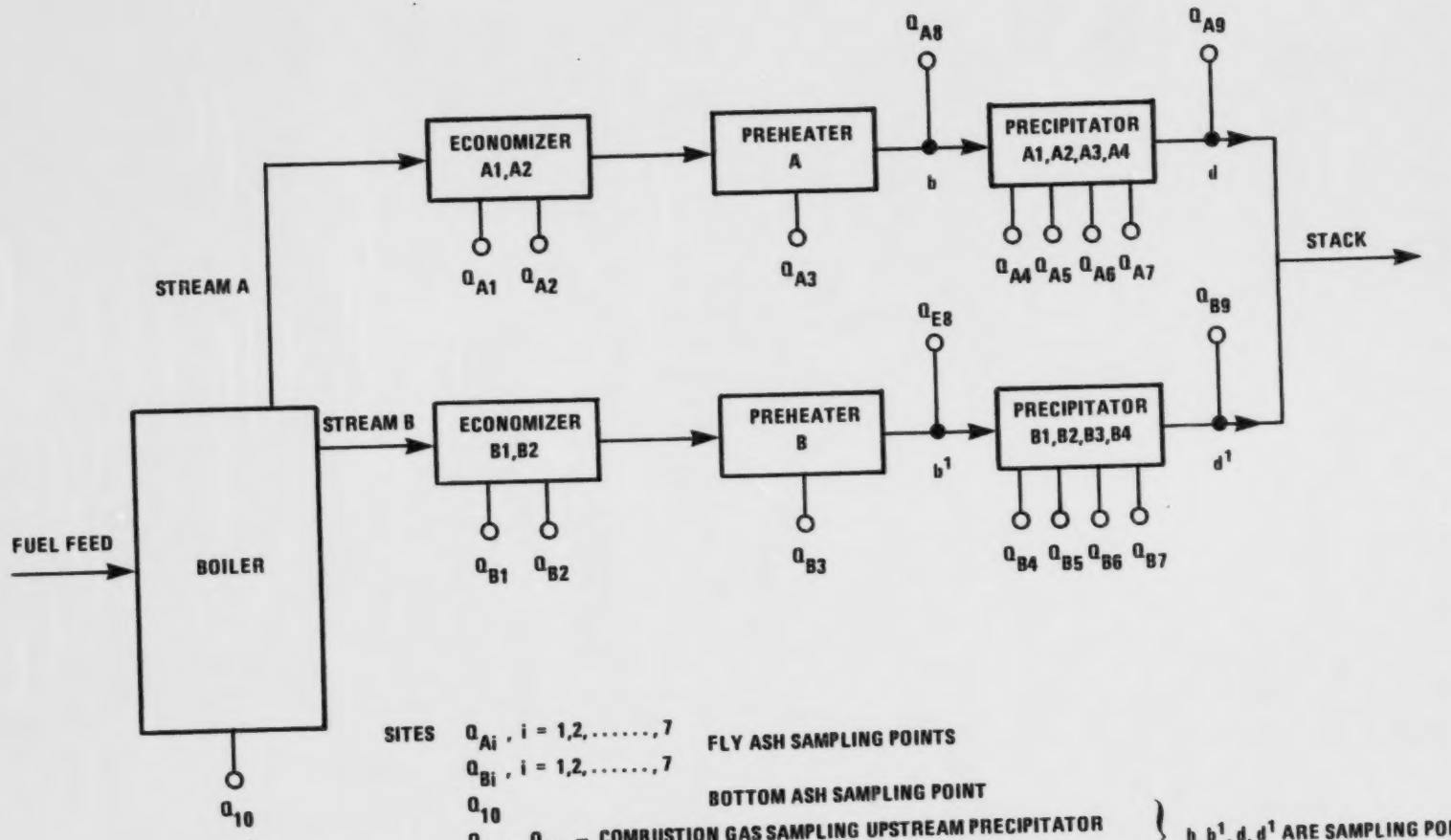
Sampling Points on Unit 1, Widow's Creek

As is indicated above, the emergent gas streams from the boiler are divided into "A" and "B" streams which thereafter pass through a number of elements. The resulting complex of sampling points is shown (in schematic form) in Figure 1.

Fly Ash Collection and Sampling

Just as the combustion gases from all six units are merged prior to their admission into the stack, so is the collected ash from the various points on the system indicated on Figure 1 as Q_{Ai}, i = 1, 2, 3, 4, 5, 6, 7; Q_{Bi}, i = 1, 2, 3, 4, 5, 6, 7; and finally Q_{10}. To better illustrate this situation, four separate collection points are indicated for fly ash on each set of precipitators. In the actual installation, these four points are collected together through what appears to be a six to eight inch line which is, in turn, connected to the lines from the other precipitators. Apparently, this line is flushed with water to remove the collected ash which ultimately is rejected to a common settling pond.

The method that is currently used for sampling this fly ash consists of inserting a sampling rod into the base of the collection bin (samples are actually taken from only the first two precipitators) and removing a sample. The first two such samples are discarded, and the third is taken as the sample for analysis. Although the interior configuration of these collection bins is not apparent, it would seem that material is stored in the lines until the containers are partially filled. When the bins are partially filled, the collected fly ash is flushed into the above mentioned flush lines. It would therefore seem that ash is collected over a considerable period of time. Because of the rheological properties of the particles, some segregation of particle size could be expected with the larger particles tending toward the bottom. A sample taken under these circumstances would therefore not be expected to be representative of the actual size distribution of the fly ash within the flue gases. When one takes into account the finding reported by Hutzinger et al.[4] that the concentration of such compounds as the PCDFs and the PCDDs is higher in the stack emitted particulates than in the ESP-collected fly ash, the acute need for a representative sample becomes obvious.



SITES Q_{Ai} , i = 1,2,.....,7 FLY ASH SAMPLING POINTS

Q_{Bi} , i = 1,2,.....,7

Q_{10} BOTTOM ASH SAMPLING POINT

Q_{A8} , Q_{B8} – COMBUSTION GAS SAMPLING UPSTREAM PRECIPITATOR

Q_{A9} , Q_{B9} – COMBUSTION GAS SAMPLING DOWNSTREAM PRECIPITATOR

} b, b^1, d, d^1 ARE SAMPLING POINTS

P_j = PCB FEED RATE

FIGURE 1 APPROXIMATE LAYOUT OF SAMPLING POINTS IN PLANT NUMBER ONE BOILER, WIDOW'S CREEK, ALA.

Bottom Ash Collection and Sampling

The bottom ash is, potentially, a significant route for the removal of uncombusted PCBs from the boiler and therefore requires careful attention. However, the physical arrangement of the base of the boiler is such that there seems to be no reasonable method by which representative samples of the bottom ash can be obtained. Further, the continuous removal of ash as it collects (again into a common disposal flush line) would appear to rule out a precise determination of the rate of formation of bottom ash.

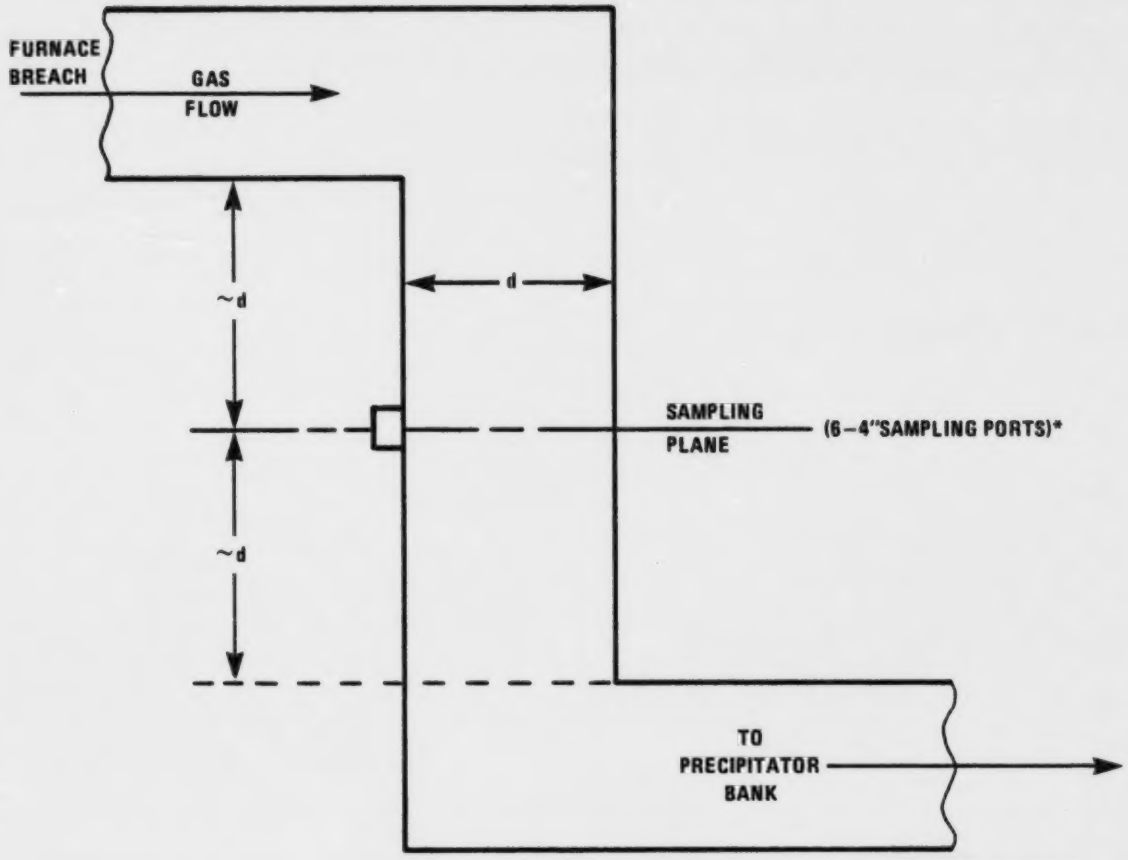
In addition to the problem of the collection of representative ash samples, the removal of the collected ash through a system that is common to all six boilers introduces the possibility of the contamination of the ash by the collection system itself. If a significant concentration of PCBs and/or several of the possible intermediates were in the ash from Boiler Number 1 resulting from the co-firing of PCBs with coal, then the entire load of ash from all six boilers would be contaminated. The magnitude of this problem and the possible impact of such contamination is not clear at this writing. At a proposed feedrate on the order of 100 gm PCB/hour, even if there were no destruction in the passage through the boiler and if all the PCB were entrained in the ash, the PCB concentration would be approximately:

$$C_{max} = \frac{100}{56 \times 2000 \times 454 \times 0.15} = 13.1 \times 10^{-6} = 13.1 \text{ ppm}$$

this is well below the concentration limit for land disposal of contaminated solids. When it is further realized that the ash from all six boilers is disposed of in the same location, the maximum possible concentration is further reduced by a factor of six. Thus, this appears to present no potential environmental problem.

Exhaust Gas Sampling

In Figure 2, there are two points for each of the split exhaust gas streams that are indicated as gas sampling points - Q_{A8}, Q_{A9}, Q_{B8}, and Q_{B9}. The geometry of these points is illustrated in the schematics in Figures 2 and 3, which show the location of the plane on the input to the precipitator and the output of the precipitator, respectively. These sites



*NOTE: THESE PORTS ARE ROUTINELY USED BY ALABAMA AUTHORITIES FOR COMPLIANCE TESTING.

FIGURE 2 RISER SAMPLING PLANE ON INPUT TO PRECIPITATOR BANK NUMBER ONE BOILER, WIDOW'S CREEK, ALA. (PLAN VIEW) (POINTS Qa8, Q68 ON FIGURE II)

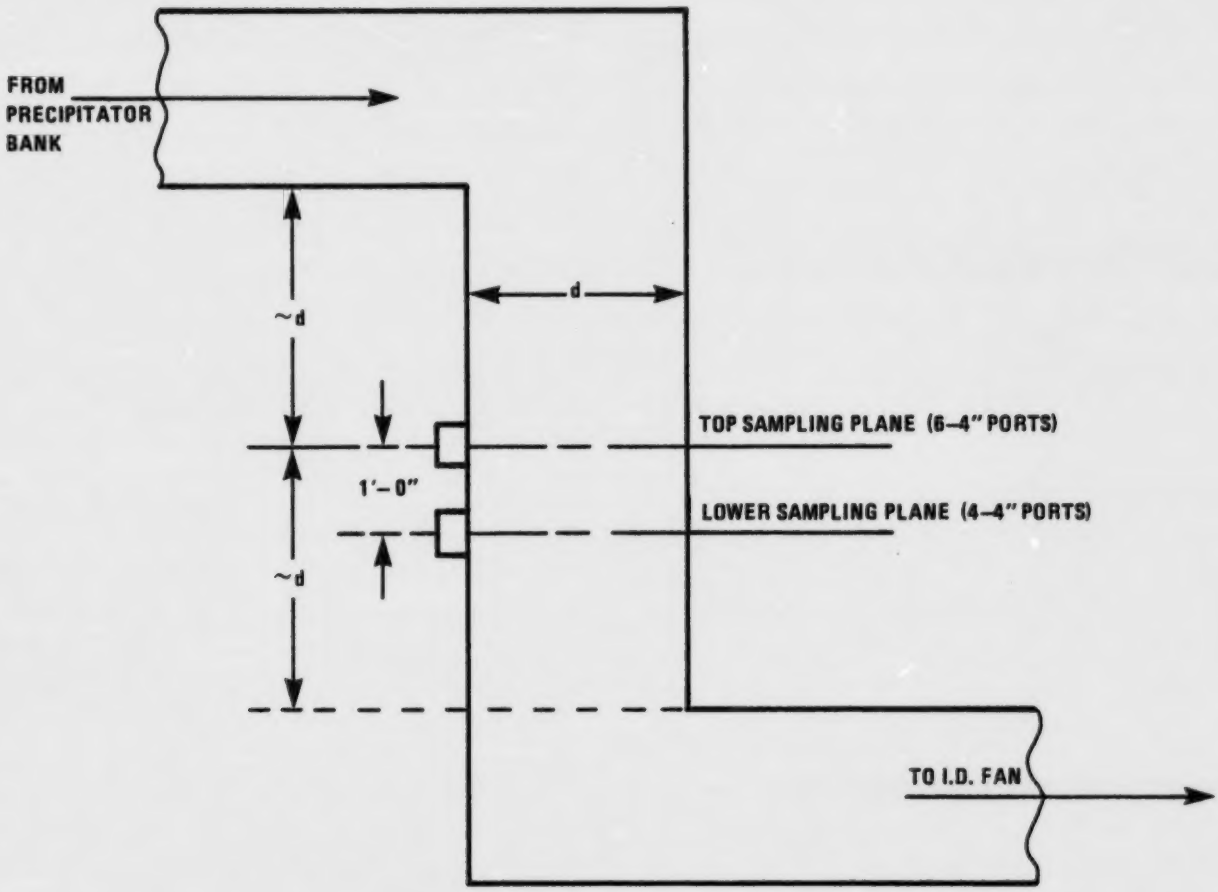


FIGURE 3 RISER SAMPLING PLANES ON PRECIPITATOR BANK OUTPUT NUMBER ONE BOILER, WIDOW'S CREEK, ALA. (PLAN VIEW) (POINTS A, B ON FIGURE 1)

are not located at points where one would expect to find ideal conditions for isokinetic sampling. However, the use of flow straighteners in the elbows, both up- and downstream, results in a velocity profile and temperature profile that are very close approximations to a good, non-turbulent flow at the sampling levels.* The alternative, as has been suggested by reviewers of this Protocol, of using a new set of sampling ports in the long (approximately 150 feet) horizontal run from the bottom of the vertical duct (as shown in Figure 2) to the ESPs introduces the real possibility of gravitational particle segregation which would probably distort the particle size distribution far more than the slight effects at the sites shown in Figure 2.

On-Stream Instrumentation

In addition to the usual control parameters, the system associated with Unit Number 1 at Widow's Creek has several items of on-stream instrumentation that are of particular interest in the proposed research effort. Specifically, there is instrumentation for the determination of excess oxygen, NO_x, SO_2, and opacity of the stack gases. A variety of internal temperatures is monitored including the input and output temperature at the reheater and the stack temperature. Unfortunately, there seems to be no on-line thermometry within the boiler itself. Additional instrumentation for continuous measurements of the rate of fuel (coal) injection and the rate of air intake as well as the rate of fuel (coal) injection and the rate of air intake as well as the rate of steam production are at the control panel. The rate of steam production might be of some value in the attempt to evaluate the effect of PCB-contaminated waste oil injection on the power generation efficiency of the boiler.

Meteorological Instrumentation

The Widow's Creek plant is not equipped with scrubbers for the elimination of SO_2 (at least for the six units of concern in this study), and therefore it has proved necessary for TVA to provide and maintain a rather extensive network of ambient air monitors to observe the ambient concentrations of

*See Section 4 (particularly Figures 6 and 7) for further discussion of the flow conditions. These sampling points have been routinely used for compliance tests of the Widow's Creek complex.

SO_2 and particulates arising from plant operation. In addition to these monitors, there is also a resident meteorological staff with the appropriate equipment to determine the standard meteorological parameters for estimation of ground dose rates. We have been assured that the services of this group would be available for the purposes of the proposed experiments.

OTHER SITE-SPECIFIC CONSIDERATIONS

Geographical Location

The Widow's Creek installation is located in northern Alabama some 35 to 40 miles southwest of Chattanooga, Tennessee. The nearest community is Bridgeport, Alabama, which is about 5 km (approximately 3 mi) to the northeast of the site. Since the population of Bridgeport is said to approximate 3000 people (Hammond World Atlas, 1977), the population at risk* from exposure is very small. The location of the site appears nearly ideal for the proposed experiments.

Isolation of Unit Number One

Although each of the units that make up the first six of the Widow's Creek installation is separate from the others, the actual expanse covered by each of the individual units is rather extensive. It would appear that there is no realistic way to completely isolate the test unit during the PCB feed experiments. The great distance between the separate sampling points suggests that the only practical approach to isolation will be roping off the pertinent sampling points during an experiment. This process will, of course, be augmented by the use of warning signs even though this can lead to unfortunate reaction from the operations crew. To avoid misunderstanding, the operations people should be thoroughly briefed before the proposed experiments begin. This activity will require the active assistance of the EPA Project Officer.

PCB Contaminated Feed and Storage

The obvious method of feeding the PCB-contaminated oil is through the oil injection nozzles. This approach will necessitate fairly significant changes

*See Section 7 for an evaluation of the estimated risk.

in the feed control and pressure control assemblies presently used for oil feed control. The nature of the suggested changes is discussed in a later section of this Protocol.* The proposed feed control system is also provided with suitable clean oil feed to allow cleanup of the contaminated nozzles after the completion of the proposed tests. It is anticipated that the contaminated waste oil will be shipped to the Widow's Creek site in a vacuum truck which will be used for the on-site storage of the material. The physical layout of Number One boiler is such that there is adequate room outside the building for parking the trailer during the tests. Some concern has been expressed by TVA operations people about the long transfer line that will be occasioned by this arrangement, but this concern has been relieved by a detailed explanation of the proposed feed system as presented in Appendix A.

On-Site Laboratory Facilities and Space

Several routine chemical and physical tests are carried out on-site. A representative example of the type of information that is available is shown in Table 2 which is a standard weekly report sheet from the Widow's Creek facility. The only major item that appears to be missing is a determination of the chlorine content of the coal (this is of interest since chlorine or hydrochloric acid should be major combustion products from the burning of PCBs). It would be useful to use the chlorine level in the stack gases in a mass balance computation. Unfortunately, the chlorine level of most coal, coupled with the rather large feed rate of fuel (about 50 ton/hr), will probably preclude availability of usable chlorine mass balance data.

*Appendix A presents a complete discussion of the feed system.

82 (PP-7-64)

TABLE 2

Bunker Sample Period ____ STEAM PLANT OPERATING STATISTICS

Plant Widows Creek

Hours 168:00

Period April 1 - 7

Item	Unit No.	1	2	3	4	5	6
1	Average Hourly Gross Load, Kw	60486	61558	72923	68774	68119	83189
2	Maximum Hour Net Generation, Mwh	115	114	128	129	124	134
3	Gross Generation, Mwh	1344	1470	12251	11554	11444	2024
4	Station Use, Mwh	177	180	985	936	959	220
5	Net Generation, Mwh	1167	1290	11266	10618	10485	1804
6	Station Use, %	13.17	12.24	8.04	8.10	8.38	10.87
7	Capacity Factor, %	5.7	6.2	48.7	48.9	48.4	8.6
8	Turbo-Gen. Avail. Factor,%	94.0	100.0	100.0	100.0	100.0	100.0
9	Boiler Avail. Factor, %	100.0	100.0	100.0	100.0	100.0	100.0
10	Unit Avail. Factor, %	94.0	100.0	100.0	100.0	100.0	100.0
11	Hours of Use	22:13	23:53	168:00	168:00	168:00	24:20
12	Turbine Startups	0	0	0	0	0	0
13	Boiler Cold Startups	0	0	0	0	0	0
14	Gross Heat Rate, Btu/Kwh	10420	11110	10790	10390	10500	10370
15	Net Heat Rate, Btu/Kwh	12000	12670	11740	11300	11460	11630
16	Boiler Efficiency, %	87.3	85.9	85.4	85.5	84.3	85.4
17	Moisture in Fuel Loss, %	0.6	0.6	0.6	0.7	0.7	0.6
18	Hydrogen Loss, %	3.7	3.7	3.7	3.7	3.8	3.8
19	Dry Gas Loss, %	6.4	5.9	7.1	6.5	7.3	8.1
20	Combustible Loss in Fly Ash, %	1.5	3.3	2.7	3.1	3.4	1.6
21	Pyrite Loss, %	0.1	0.2	0.1	0.1	0.1	0.1
22	Fixed Losses, %	0.4	0.4	0.4	0.4	0.4	0.4
23	Total Losses, %	12.7	14.1	14.6	14.5	15.7	14.6
24	Throttle Pressure, Psig	1425	1425	1457	1436	1846	1800
25	Throttle Temperature, °F	995	990	1003	1004	999	1000
26	Interceptor Valve Temperature, °F	-	-	-	-	926	985
27	Exhaust Pressure, In. Hg. Abs.	1.38	0.99	1.11	0.69	0.79	0.71
28	Intake Water Temperature, °F	54	54	55	55	55	54
29	Air Temp. Ent. Air Htrs., °F-Avg.	108	103	115	106	96	118
30	Gas Temp. Lvg. Air Htrs., °F-Avg.	313	298	345	323	359	388
31	Dry Gas Loss Air Temp., °F	60	60	60	60	60	60
32	Throttle or Feedwater, M Lbs.	11025	12030	100529	94795	80398	14086
33	Superheat Attemperation, %	2.37	5.08	3.05	2.06	5.58	3.55
34	Reheat Attemperation, %	-	-	-	-	1.73	0.76
35	Makeup, %	3.05	1.69	1.92	1.62	1.66	1.44
36	Building Heating Steam, %	-	-	-	-	-	-
37	Total Air at Boiler Outlet, %	124	121	123	121	121	123
38	Total Air at Air Heater Outlet, %	134	131	133	131	129	131
39	Coal Fired, M Lbs.	1174.0	1357.0	11141.0	10240.5	9879.0	1720.0
40	Combustibles in Fly Ash, %	9.8	21.5	16.5	18.0	25.1	11.4
41							
42							
43							
44							

Fuel Analysis - As Fired					
M	VM	FC	Ash	Btu	S
6.4	28.2	51.6	13.8	11930	0.8
6.3	28.2	53.2	12.3	12040	0.7
6.5	27.3	52.1	14.1	11870	0.7
6.9	26.7	52.2	14.2	11720	0.7
7.7	30.6	51.1	10.6	12160	0.7
6.2	27.6	53.3	12.9	12200	0.8
-	-	-	-	-	-
9.3	36.2	43.0	11.5	11510	4.0

Unit Group No.	Coal Est. %	Fuel Oil Fired Gal.	Btu/Gal.	S	Max. Hour Net Gen. Mwh	Time	Date
Plant							

Outside Temperature, Avg.-Max.-Min., °F

Remarks:

SECTION 3

GENERAL CONSIDERATIONS

COMBUSTION GASES

The combustion gases from the boiler are divided into two separate streams, each of which is fed through economizers and thence to four electrostatic precipitators in a cascade configuration. The cleaned gases are then admitted to a plenum which feeds the stack; three of the boilers feed each side of the stack. To estimate the flow rate and the composition of the combustion gases, we consider the following analysis.

The coal feed is a nominal 5×10^4 kg/hr (56 tons/hr) which is assumed to be 80% carbon (Table 2). It is further posited* that the air input is such that there is 15% excess over stoichiometric (Table 2). Then, from the equation

$$C + O_2 = CO_2 \qquad \text{(Eqn. 1)}$$

for a feed rate of 4.06×10^4 kg/hr (8.96×10^4 lb/hr) of C, the stoichiometric O_2 requirements amount to 1.08×10^5 kg/hr (2.39×10^5 lb/hr). Allowing for a 15% excess, the total O_2 input becomes 1.24×10^5 kg/hr (2.74×10^5 lb/hr). Air, containing 23.2% O_2 by weight, must then be supplied at the rate of 5.25×10^5 kg/hr (1.16×10^6 lb/hr). The rate of production of CO_2 is then 1.49×10^5 kg/hr (3.29×10^5 lb/hr). The properties of the combustion gases are thus as presented in Table 3.

*Information obtained from Widow's Creek operation's staff.

TABLE 3. ESTIMATED COMPOSITION OF COMBUSTION GASES

Gas	Mass Flow Rate (kg/hr)	(lb/hr)	% by Weight	% by Volume
N_2	4.01×10^5	(8.84×10^5)	70.8	78.67
O_2	1.6×10^4	(3.53×10^4)	2.83	2.74
CO_2	1.49×10^5	(3.29×10^5)	26.3	18.58
Total	5.66×10^5	(1.26×10^6)		

The average molecular weight of the combustion gases is, based on Table 3, 32.27.

The estimated flow rate through the ducting may then be computed by taking the average temperature at the output of the economizer to be 180°C (370°F), as reported by TVA personnel. Making the necessary conversions results in an estimate of a total flow of combustion gases of 1.08×10^4 m^3/min (3.83×10^5 ft^3/min). If it is assumed that all six boilers are in operation and exhibit essentially the same combustion gas production rate, then the total estimated flow through the stack can be taken as approximately 6.5×10^4 m^3/min (2.3×10^6 ft^3/min).

Returning to the combustion gas generation rate for a single boiler, and using the boiler dimensions as given above, the approximate volume of the boiler is 4.53×10^3 m^3 (1.6×10^5 ft^3). Now the exhaust temperature is taken to be 180°C (370°F) while the actual flame temperature is in excess of 1650°C (3000°F). Using the estimated gas production rate, we may estimate the residence time as between 25 seconds (if the internal temperature were as low as 180°C) to something less than 5 seconds (if the entire region were at the flame temperature). Clearly, the conditions that exist within the power boiler are consistent with those required by the Regulations for PCBs disposal.

The above calculations are, at best, estimates since many of the values assigned to parameters are only themselves approximate. A further consideration is the fact that analyses of the fly ash show that not all the combustible material is consumed (Table 1) so that the carbon input rate tends to be slightly higher than the rate at which carbon is consumed. An interesting sidelight on this point (communicated by TVA personnel) is that there is

apparently a considerable difference in the concentrations of residual combustibles in the fly ash derived from two parallel combustion gas streams from the Number One boiler at Widow's Creek. This division of the emergent gases from the boiler is apparently a reflection of the internal division of the fire box into two separate high temperature regions by the double set of tubes running through the center of the fire box. It would then appear that the observed differences in the residual combustibles on the fly ash between the two streams could be caused by slight differences in the residence time-temperature regimen in the two separate regions of the fire box. The possible significance of this explanation will be discussed below in the section dealing with the interpretation of the experimental results.

FEED RATE CONSIDERATIONS

A supply of 2.8×10^4 l (7500 gal) of PCB-contaminated waste oil with PCB concentrations of the order of 83 ppm has been proposed for the present experiments. As previously mentioned, the oil injection nozzles have been designed to feed 76 l/hr (20 gal/hr) at the design pressure of 7×10^4 kg/m^2 (100 psi). Presumably, the atomization of the oil is optimized at the design feed rate and pressure; hence it is proposed that the PCB-contaminated waste oil be fed through these nozzles at the design rate and design pressure. To estimate the possible PCB feed rates, assuming that the oil has a density of 900 kg/m^3 (56.15 lb/ft^3), a concentration of 83 ppm corresponds to a feed (at 76 l/hr of waste oil feed) rate of 5.65 gm/hr of PCBs. From Table 3, the estimated rate of production of combustion gases is 5.66×10^5 kg/hr; hence the expected PCB concentrations for various feed rates and various estimated PCB destruction ratios may be computed. The results of these calculations are summarized in Table 4.

TABLE 4. ESTIMATED PCB CONCENTRATIONS IN EFFLUENT GASES

Oil Feed Rate		PCBs Concentration in Stack Gas			
		0% Destruction		99.9% Destruction	
(l/hr)	(gal/hr)	(ppb)	(gm/l)	(ppb)	(gm/l)
76	(20)	10	8.68×10^{-9}	0.01	8.68×10^{-12}
228	(60)	30	2.60×10^{-8}	0.03	2.6×10^{-11}
456	(120)	60	5.2×10^{-8}	0.06	5.2×10^{-11}

Detection Sensitivity Considerations

We now estimate the probable analytical detectability of the assumed concentration levels on Table 4 by positing that sampling of the effluent gases is accomplished at a rate of 15 l/min at 36 points in the ducting and for 7 minutes at each sampling point (see section on sampling). The total collected sample (at 30°C) is then 3.78 m^3 which, at the assumed temperature in the duct of 180°C, corresponds to 5.65 m^3. If we now further assume that the only route by which unburned PCBs are lost from the system is through the effluent gases (no association of PCBs with the bottom ash or with the fly ash collected within the economizer), then the computed concentrations from Table 4 allow the estimate of the absolute quantity of collected PCBs. The results of these calculations are summarized in Table 5.

TABLE 5. ESTIMATED PCB SAMPLE SIZE CORRESPONDING TO SAMPLING AT 15 l/MIN FOR 7 MIN AT EACH OF 36 POINTS

PCB Concentration in Combustion Gases (ppb)	PCB Sample Size (gm)
.01	4.9×10^{-8}
.03	1.47×10^{-7}
.06	2.94×10^{-7}
10	4.90×10^{-5}
30	1.47×10^{-4}
60	2.94×10^{-4}

Thus, it appears that the selected feed rates of 76 l/hr, 228 l/hr, and 456 l/hr with 83 ppm PCB contaminated waste oil should allow adequate sensitivity provided that there are no appreciable losses through the bottom ash or the fly ash.

Assuming that it is consistent with the PCB Disposal Regulations,[1] the PCB contamination will be increased from the present 83 ppm to something like 450 ppm. This would effect an approximately 5-fold increase in the levels of PCBs to be found in the stack. The sensitivity data in Table 4 would then be increased by the same factor of approximately 5.

Thermal Effects of Proposed Feed Rates

To estimate the thermal consequences of the proposed waste oil feed rates, we take the thermal value of the waste oil to be similar to that of diesel oil, 2172 kcal/kg (19000 Btu/lb). Then the estimated differential thermal input resulting from the proposed waste oil feed rates can be estimated as shown in Table 6.

TABLE 6. THERMAL INPUT DUE TO WASTE OIL INJECTION

Waste Oil Feed Rate				Thermal Input		Ratio of Oil Thermal Input to Coal Thermal Input
(l/hr)	(gal/hr)	(kg/hr)	(l/hr)	(kcal/hr)	(BTU/hr)	(per cent)
76	20	68.5	151	7.23×10^5	2.87×10^6	0.22
228	60	205.9	454	2.17×10^6	8.63×10^6	0.67
456	120	411.4	907	4.35×10^6	1.72×10^7	1.34

For Table 6, the coal feed is taken to be 5×10^4 kg/hr (56 tons/hr), and the average thermal value of the coal is 1.31×10^3 kcal/kg (11500 Btu/lb). The nominal thermal input of 3.25×10^8 kcal/hr (1.29×10^9 Btu/hr) is then 3.75×10^8 watts or 377.5 megawatts. The nominal electrical output of the system is taken to be 125 megawatts so that the overall efficiency is approximately 33%. The maximum effect of the waste oil feed is an increase of 1.34% in energy input, and therefore the proposed experiments should have a negligible effect on the thermal and electrical efficiencies of the system.

POSSIBLE EFFECTS OF INCREASING PCB CONCENTRATION BY ADDITION OF MORE PCBS

As has been discussed above, at the concentration level of 83 ppm, it appears that the analytical sensitivity of the experiment at the proposed feed rates will be adequate to meet program purposes. On the other hand, all the factors that affect sensitivity would be significantly enhanced if it were possible to add PCBs to the available waste oil so as to increase the concentration to a level of the order of 450 ppm. The result would be essentially a 5-fold increase in PCB concentrations within the effluent gas stream with the corresponding 5-fold increase in the quantity of material that is collected for the assumed sampling rates. In spite of the ambiguity of the PCB Disposal Regulations as to the propriety of spiking the oil sample to increase the PCB

concentration, the precedent set by the recent test burn at the GM plant (private communication for EPA Project Officer) seems to allow such spiking. It is estimated that the total oil to be used for these experiments will be of the order of 6800 kg (2000 gal with density .9 kg/liter). If the present PCB concentration is taken to be less than 50 ppm (the effective concentration has been reduced in the available oil by the addition of newly contaminated material to the bulk storage vessel), then the addition of 1.75 l of Aroclor 1254 (with density of 1.53 kg/l) will result in a final concentration of slightly less than 450 ppm.

The effect of this spiking of the feed material is simply to increase the projected sample size (as indicated in Tables 4 and 5) by a factor of approximately five. In other words, with the given detection sensitivity it should be possible to increase the sensitivity of the experiments by a factor of five. On the other hand, the assumptions that have been made in deriving the estimates in Tables 4 and 5 of the amount of PCB and PCB-derived intermediates carried by the fly ash and by the bottom ash might result in an effective increase in sensitivity of something less than the projected factor of five.

PCB DESTRUCTION EFFICIENCY

The destruction efficiency for combustion of a refractory compound can be expressed as:

$$\text{Destruction Efficiency (DE)} = \frac{\text{Feed rate-Effluent rate}}{\text{Feed rate}} \times 100 \quad \text{(Eqn. 2)}$$

The significance of the feed rate and its measurement is obvious, but the effluent rate requires further discussion. The effluent streams from the system consist of the effluent combustion gases, the fly ash collected in the economizer and in the precipitators, and the bottom ash. The schematic in Figure 1 shows the approximate relationship of these various streams.

The major experimental difficulty with the Widow's Creek boiler installation lies in the fact that there seems to be no obvious way to determine the rates of production of the ash from the various collection points. To illustrate the nature of this problem we consider below the rate at which PCBs are carried out of the system by the bottom ash, which is produced at an average rate Q_a and which contains an average concentration of PCBs represented by C_a. Then the rate of removal of PCBs is given by the product

$Q_a C_a$. Let the uncertainty in the production rate be given by dQ_a and the uncertainty in the PCB concentration by dC_a. Then the rate at which PCBs are carried out of the system via the bottom ash is given by the expression:

$$Q_a C_a \pm (C_a dQ_a + Q_a dC_a),$$

where terms involving the products of the uncertainties have been neglected. To now extend this argument to the definition of the destruction efficiency (DE), we write Equation (2) in the following form:

$$DE = \frac{P - \sum_{i=1}^{n} \{ Q_i C_i + (Q_i dC_i + C_i dQ_i) \}}{P}, \qquad \text{(Eqn. 3)}$$

where P is the input PCB feed rate. Now, Equation (3) may be written in the more informative form shown in Equation (4).

$$DE = (DE)_{ACT} \pm \Delta(DE) \qquad \text{(Eqn. 4)}$$

where:

$$(DE)_{ACT} \equiv 1 - \frac{1}{P} \sum_{i=1}^{n} Q_i C_i \qquad \text{(Eqn. 4')}$$

$$(\Delta DE) \equiv \frac{1}{P} \sum_{i=1}^{n} (Q_i \delta C_i + C_i \delta Q_i) \qquad \text{(Eqn. 4'')}$$

In Equations (3) and (4), the index (i = 1,2,..... n) represents the various effluents of the system; $(DE)_{ACT}$ refers to the actual destruction efficiency.

Unfortunately, the usual methods of dealing with experimental error are not applicable to the problem of the determination of the most probable value of DE. These methods are applicable in those situations wherein the uncertainties arise from random errors. The uncertainties of concern, those involving the production rate of the ash, must be considered to be systematic errors. One approach to dealing with the difficulty in determining the ash production rates lies in the possibility of a material balance in the ash. Given the rate of injection of coal and the average ash content of the coal, the rate of production of ash can then be estimated. It is necessary in this case to assume that all of the combustibles are removed within the furnace

so that the actual ash production rate can be estimated; this assumption is questionable since there appears to be a considerable residual combustible content of the ash (Table 1). If, by proper application of EPA Method 5 for particulates within the transfer duct from the furnace breach to the precipitators, it is possible to accurately estimate the rate of production of fly ash, then by subtraction, the rate of collection of bottom ash and economizer collected ash can be estimated; to the extent that this method is practical, the uncertainty in DE can be estimated.

One further complication in the material balance approach lies in the fact that the boiler must be operated for some hours before PCB-contaminated waste oil injection is initiated in order to assure that equilibrium conditions exist. During this operational period there will, of course, be considerable ash collected at each of the collection points. This ash must be removed prior to sampling because, otherwise, there would be no way to determine the adequacy of the sampling for PCB content. It is not clear that this is a practical requirement in terms of the actual system.

HCl PRODUCTION

Since one of the major combustion products from PCBs will be HCl, there is the possibility that a measurement of the HCl concentration in the effluent gases might seem to be an alternative method of determining the destruction efficiency of the boiler. Unfortunately, most coals contain significant concentrations of chlorine.[8] To estimate the situation that we can anticipate, consider that the average chlorine concentration of the coal is 0.1%. Then, at the assumed feed rate of 5×10^4 kg/hr (56 tons/hr), the combustion gases would be expected to contain significant levels of HCl. The actual estimated production rate would be 871 g/min. On the other hand, for a PCB feed rate of 5.66 gm/hr (76 l/hr at 83 ppm), the HCl production from the PCBs (assuming that the PCBs are from Aroclor 1254) would amount to some 0.052 g/min. Clearly, the expected variation in coal feed rate coupled with the probable variations in chlorine content of the coal make a determination of the differential HCl production due to the PCB destruction impossible.

SECTION 4

EXPERIMENTAL DESIGN

The purpose of the proposed experiments is the (1) determination of the destruction efficiency for PCBs injected into a coal-fired power boiler and (2) a determination of the effect of such cofiring on the efficiency of the boiler. It would be of special interest if it were possible to alter the combustion conditions within the boiler in the course of these experiments in order to determine the effect of such parameters as coal feed rate, boiler temperatures and excess oxygen on the PCB destruction efficiency. Since the boiler that has been tentatively selected is expected to be on-stream for power generation, it will not normally be possible to alter these operating parameters. On the other hand, the variable that is readily altered is the feed rate of the PCB-contaminated oil. Calculations presented in Section 3.0 indicate that, even at the highest proposed feed rate, 466 l/hr (120 gal/hr), the effective energy input from the thermal value of the oil will not exceed 1.3% of that from the coal. Thus, varying the oil feed rate should have little effect on the total rate of chemical energy release and consequently little effect on the operating parameters of the boiler. On the other hand, the combustion of this quantity of oil will result in a depletion of the excess oxygen, assuming that the excess air is maintained constant, and therefore could affect the thermal efficiency as measured by the ratio of the concentration of CO to that of CO_2 in the exhaust gases.

PROCEDURAL REQUIREMENTS

Before the beginning of the actual test burns, a number of procedural steps will be necessary. Because of the significant emotional response to a proposal that PCBs or PCB-contaminated materials are going to be incinerated, it is essential that all concerned agencies and persons be fully informed of the nature of the experiment, the measures that will be taken to ensure

safety, and the provisions that have been taken to limit the effects of an accident (a spill, for example). Since the proposed tests will be conducted in a TVA facility located in northern Alabama under EPA sponsorship, it follows that the agencies that are concerned are TVA, EPA Region IV, Alabama, and the EPA/RTP.

The approvals that are required from TVA include the decision by high management that such a test is in the interest of TVA, approval by the Health and Safety Group, by the Engineering Group, and by the operations staff at Widow's Creek. Steps have been taken to fully inform the top management of TVA, and at this writing, there has been official notification that the tests were approved by TVA. In order to fully inform the Health and Safety Group as well as the Engineering Staff, there have been several face-to-face meetings at which the details of the various aspects of the proposed work have been carefully examined. It is anticipated that the Health and Safety Group will establish the requirements for personnel safety that will be met at the site during the tests. The proposed PCB-contaminated oil feed system has been examined by the Engineering Staff and found to be satisfactory for the purpose.

During the planning stages of this program, EPA Region IV, Headquarters, and RTP have been fully informed and in close contact with the contractor. Approval by the authorities of Alabama is required for tests such as are contemplated so that efforts have been made to keep them fully informed and to solicit suggestions that would increase the acceptability of these experiments to the general public. Specifically, the Alabama Air Pollution Control Commission has been fully cooperative and very helpful.

CONTAMINATED WASTE OIL SUPPLY

It has been stated that there exists a supply of some 28400 l (7500 gal) of waste oil contaminated with PCBs at an average level of 83 ppm.* This material could be made available for these experiments. If the experiments, each of ten hours duration, are carried out at the feed rates suggested in Table 7 this would be an ample supply.

*Most recent information indicates that the PCB level may be below 50 ppm.

TABLE 7. SUGGESTED FEED RATES FOR EXPERIMENTAL STUDY

Experiment No.	Feed Rate (l/hr)	Feed Rate (gal/hr)	Duration (hours)	Total Volume Required (l)	Total Volume Required (gal)
1	76	20	10	760	200
2	228	60	10	2280	600
3	456	120	10	4560	1200
			Totals	7600	2000

Table 7 shows that the total volume of contaminated oil required is approximately 7600 l (2000 gal). The available oil is, according to TVA sources, stored in an unused transformer shell and is therefore probably contaminated with particulates. It will therefore be necessary to filter the material prior to its use for the proposed experiments. Since the source is somewhat remote from the Widow's Creek (i.e., located at the TVA facility in Muscle Shoals) a tank truck of suitable size will be required for the transport of the material to the Widow's Creek site. The filtration could most easily be carried out during the process of transferring the stored material to the tanker.

The fact that there is considerable space available on the feed face of the boiler suggests that the transport tanker might just as well be used as the on-site reservoir for the PCB-contaminated oil during the experiments. This would eliminate an extra transfer step with its attendant possibilities for a spill and the subsequent contamination of the feed face and the surrounding area.

FEED TECHNIQUES FOR PCB-CONTAMINATED OIL

As has been pointed out, the initial startup of the boiler is accomplished with fuel oil feed through up to 16 injectors on the feed face of the boiler. In usual practice, either four or eight of the available nozzles are used. Startup usually requires some five to ten hours, after which time the oil feed is shut off. These nozzles are designed to produce optimum atomization when fed at a rate of 76 l/hr (20 gal/hr) at an ambient pressure of 7.4×10^4 kg/m^2 (100 psi). The pressure and feed rate are controlled using a regulator rack located on the feed face near the injectors.

It is important, from the points of view of cost, safety and availability, to use the present nozzles for the injection of the PCB-contaminated oil. This will require some alteration of the control system since the nozzles are apparently operated in sets of two from the same oil source and from a common pressure source. The criteria for such a PCB-contaminated oil feed and the necessary control and safety features are discussed in the next section.

FEED SYSTEM

A system has been designed for feeding PCB contaminated mineral oil into the spray nozzles of Boiler Number 1. The system will be based on the following premises: (1) the vessel containing the PCB contaminated mineral oil will be positioned no further than 200 feet from the spray nozzles; (2) the PCB contaminated mineral oil will be filtered (before transfer to the storage vessel) so that the mineral oil will be as clean (in terms of particle size of suspended matter) as No. 2 fuel oil presently injected into Boiler Number 1 during cold start-up; and (3) feeding rates of 20, 60, and 120 gallons per hour will be used during the incineration tests.

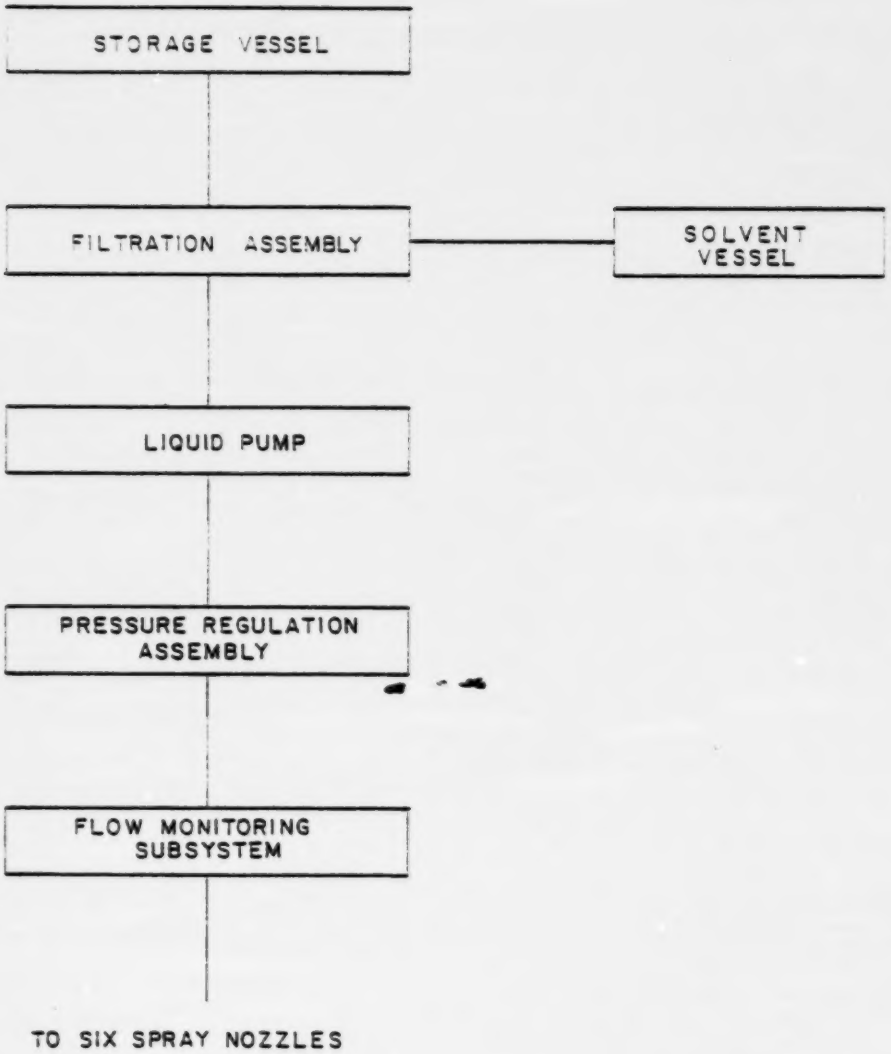
Purpose of the Feed System

The purpose of the feed system will be to supply up to 6 spray nozzles in Boiler Number 1 with 20 gallons per hour per nozzle of PCB contaminated mineral oil (feed solution) for the duration of each incineration test.

Brief Description of the Feed System

In the overall design of the feed system, prevention and containment of accidental leaks will be given the highest priority.

The feed system can be functionally broken down in terms of its six major subsystems, which are presented, in block diagram form, in Figure 4. The system will include a storage vessel for the containment of the feed solution, a filtration assembly for extra clean-up of the feed solution (if required), a liquid pump to pressurize the feed solution for its transfer (through the long distance of hydraulic lines) and its nebulization by the spray nozzles, pressure regulation assembly to accurately control the pressure of feed solution to the spray nozzles, and a flow monitor subsystem to measure the quantity of feed solution supplied to the spray nozzles. In addition, a solvent vessel will be provided for the storage of clean fuel oil required for cleanup of the feed system during the final incineration test.



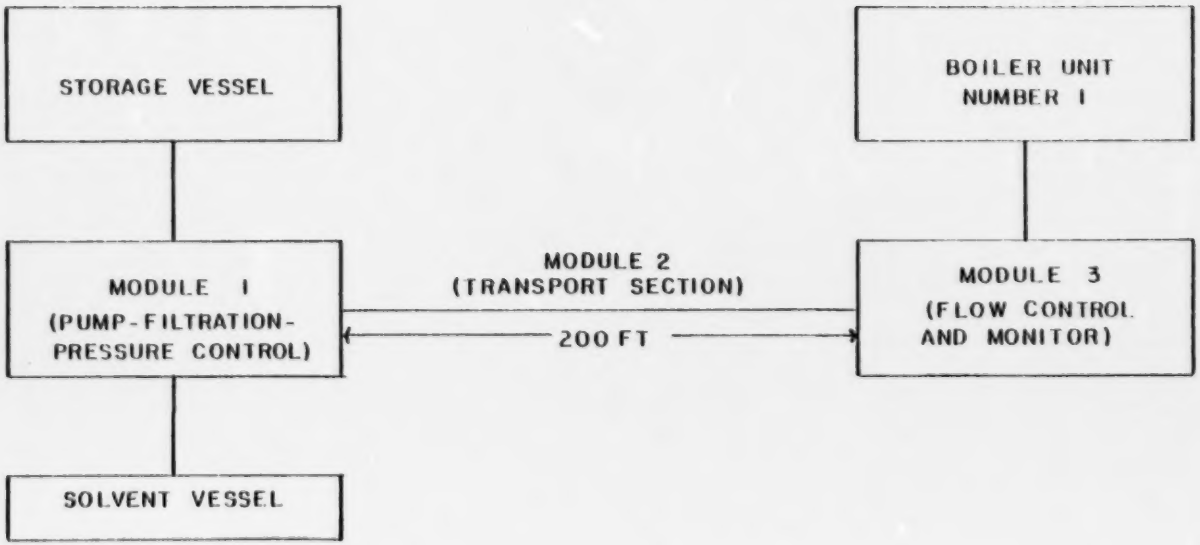
FUNCTIONAL DESCRIPTION OF FEED SYSTEM

FIGURE 4

Basically there will be three modules of the feed system. Module 1 will contain the pump, filtration, and pressure control assemblies and will be physically located near the storage vessel. Module 2 will consist of the 200-foot transport section which will transfer the feed solution from module 1 to module 3. Module 3 will consist of the flow control and monitoring hydraulic components which will be located near the site of Boiler Number 1. This layout is diagramed in Figure 5.

The solvent vessel will be located near module 1 and will probably be the tank truck used to transport the PCB-contaminated oil to the site.

The detailed design of the PCB-contaminated waste oil feed system is included as Appendix A to this Protocol.



RELATIVE LOCATION OF FEED SYSTEM COMPONENTS
FIGURE 5

BOILER OPERATIONAL PARAMETERS

The proposed PCB-contaminated oil incineration experiments are designed so that the data derived can be used to determine operating conditions under which such material can be disposed of in a power boiler with acceptable destruction rates. To accomplish this end, the actual operating parameters will have to be known during the test burns and used to correlate with the observed destruction ratios. These comparisons will determine the range of operational variables for routine operations which will guarantee proper control of emissions.

Two types of operational variables are of interest (a) the normally controlled and measured variables that are used for the determination of the operation of the boiler during normal power generation operations and (b) those variables that will be monitored specifically for the purposes of these test burns. Those variables in class (a), which are usually monitored by TVA personnel, include the following:

- Coal feed rate
- General coal analysis (as shown in Table 2)
- Air input rate to boiler
- Residual O_2 in exhaust
- Furnace pressure; internal temperature (locations on Table 2)
- Steam generation parameters
- Residual CO/CO_2 concentrations in exhaust gases.

It is anticipated that these data will be made available to the EPA contractor at the completion of each test burn.

The parameters in class (b), the measurement of which will be the responsibility of the contractor, will include the following:

- PCB-contaminated oil feed rate and total amount fed
- Furnace temperature(s)
- Fly ash particulate load
- Combustible residue in fly ash*
- Bottom ash production rate
- Gas flow rate in duct upstream and downstream of ESPs

*Confirmation by contractor since this is normally determined by TVA personnel.

- Concentration of organics in gas stream
- CO/CO_2 ratio in flue gases
- Concentration of organics (with identification of the relevant species) in the fly ash as well as in the bottom ash
- A determination of the chlorine content of the coal
- A determination of the PCB concentration in the feed material
- Residual O_2 in flue gases*

Since the parameters listed in class (a) are routinely recorded by TVA personnel, these will not be discussed further. Those parameters in class (b) are discussed below.

PCB FEED RATE/TOTAL FED

The schematic diagram of the PCB feed system (Appendix A) indicates that the feed system is equipped with an integral rate meter as well as a flow totalizer. In addition, provisions have been included for the automatic extraction of a representative sample of the PCB-contaminated oil during the feed experiments. The analysis of this, coupled with the recorded liquid feed rate, will allow the determination of the PCB feed rate during the experiment. This method of averaging the flow and the concentration will produce no distortion of the situation since the gas stream sampling will, itself, result in an average over several hours.

FURNACE TEMPERATURE

An important parameter in the destruction of such refractory compounds as PCBs is the maximum temperature to which they are exposed. It appears that there are no specific provisions in the Widow's Creek facility to determine the "furnace temperature" as such. On the other hand, there should exist some correlation between the fuel feed rate (or the output demand) on the temperatures that exist within the boiler. It is proposed that, during the background runs, a series of optical pyrometer measurements of the (background) furnace temperature be made. These measurements will then be compared to the instantaneous (to the degree that such instantaneous measurements are available) coal feed rate and the steam generation rate. This procedure will be continued during the test burns with the object being to correlate the observed temperature with either the feed rate or the steam generation

*Confirmation only.

rate or perhaps both. This information will be of value later when it becomes necessary to establish the minimum conditions under which PCB destruction can be safely carried out.

FLY ASH PARTICULATE LOAD

The installation at Widow's Creek (of which Boiler Number One is the selected experimental test bed) consists of six identical boiler units operating with a common fuel source and a common ash and fly ash disposal system. Each of the boilers is configured in such a way that the exhaust gases from the boiler are split into two streams, each of which is subsequently passed through a bank of four precipitators in cascade. Ash is collected at several points along the ducting, including a point at the economizer, as well as at the base of each individual precipitator unit (see Figure 1 for a schematic of the system). In addition, bottom ash is collected from each of the boilers.

Sampling of the ash collected at each of these points is important since it is anticipated that the ash will be a significant potential means for the removal of uncombusted PCBs and intermediate combustion products from the system. The difficulty of this procedure lies in the fact that, because of the design of the system, there is no assurance that an adequate sample can be obtained. In this context, "adequate" means representative both in particle size and nature, as well as in PCB concentration.

A second difficulty with the arrangements at Widow's Creek lies in the fact that there is no direct method of determining the rate of ash collection at any of the sampling points within the system. To illustrate the significance of this effect, we consider the following possible situation. Assume a pulverized coal feed of 5.08×10^4 kg/hr (56 ton/hr) which contains 15% ash.* If the usual relationship between fly ash and bottom ash of 4:1 is taken to be correct, then the rate of production of fly ash should be approximately 6.08×10^3 kg/hr (3.36×10^3 lb/hr). Then, from Equation 4", we have:

$$\Delta DE = \pm \frac{1}{P} \left\{ Q_f \Delta C_f + C_f \Delta Q_f + Q_b \Delta C_b + C_b \Delta Q_b + Q_g \Delta C_g + C_g \Delta Q_g \right\} \qquad \text{(Eqn. 5)}$$

where the subscripts f, b and g refer to the fly ash, bottom ash, and gas phase, respectively. We may assume that, since the quantities derived from the gas

*See Table 2.

phase are long-term averages (sampling time of the order of 250 minutes), we do not need to consider the terms that involve the gas phase. We may now estimate the effect of the remaining terms in Equation 5 by approximating that the concentrations (of PCBs) in both the bottom ash and in the fly ash are essentially equal and, since the physical state is not expected to be significantly (aside from particulate size) different, that the uncertainty in the concentration should be essentially the same for both forms of ash. If we further assume that the uncertainty in the estimation of the relative production rates is on the order of 10%, then evaluation of Equation 5 yields:

$$\Delta DE \sim \pm \frac{1}{P}\left\{1.7 \times 10^{4} \ (\Delta C) + 1.7 \times 10^{3} \ C\right\} \qquad \text{(Eqn. 6)}$$

At the concentrations that are expected (near detection limits), it can be assumed that the uncertainty in the concentration could be as much as 20%, so that Equation 6 reduces to:

$$\Delta DE \sim \pm \frac{5.1 \times 10^{3} \ C}{P} \qquad \text{(Eqn. 7)}$$

Alternative Method for Determining Ash Production Rates

The ash content of a coal sample is obtained by ignition of the sample in air under such conditions as to remove all of the volatiles. In the actual combustion of the pulverized coal, a significant fraction of the combustibles is carried off with the ash, so that the actual rate of ash production exceeds that which would be expected from the product of the ash content times the rate of firing of the coal. This implies that it will be necessary to determine the residual combustible content of the ash so that an "effective ash content" can be derived. Using the effective ash content, one can estimate the rate of bottom ash formation by obtaining the difference between the estimated ash rate production and a measured fly ash production rate. The latter can be determined by direct application of EPA Method 5 to the flue gases at points b and b' of Figure 1 upstream of the precipitator cascade.

It was pointed out in the Preliminary Evaluation of the Widow's Creek Facility, the existing sampling ports are located in vertical sections of the ducting both before and following the ESPs. There was some question about the adequacy of the upstream sampling site in that the section appears to be

too short to allow the full establishment of non-turbulent flow. Since it is at this point that an attempt will be made to determine an accurate value for the fly ash production rate, it is essential that the conditions suitable for isokinetic sampling exist. A careful examination of several representative series of velocity pressure measurements* made at this site seems to indicate that the flow straighteners that have been added above and below the sampling plane do, indeed, result in a close approximation to the required conditions. An example of the measured velocity pressure (actually presented as the square root of the measured velocity pressure which is proportional to the velocity) as a function of position within the duct is shown in the Figure 6; the temperature distribution is shown in Figure 7, both results taken at point b in Figure 1.

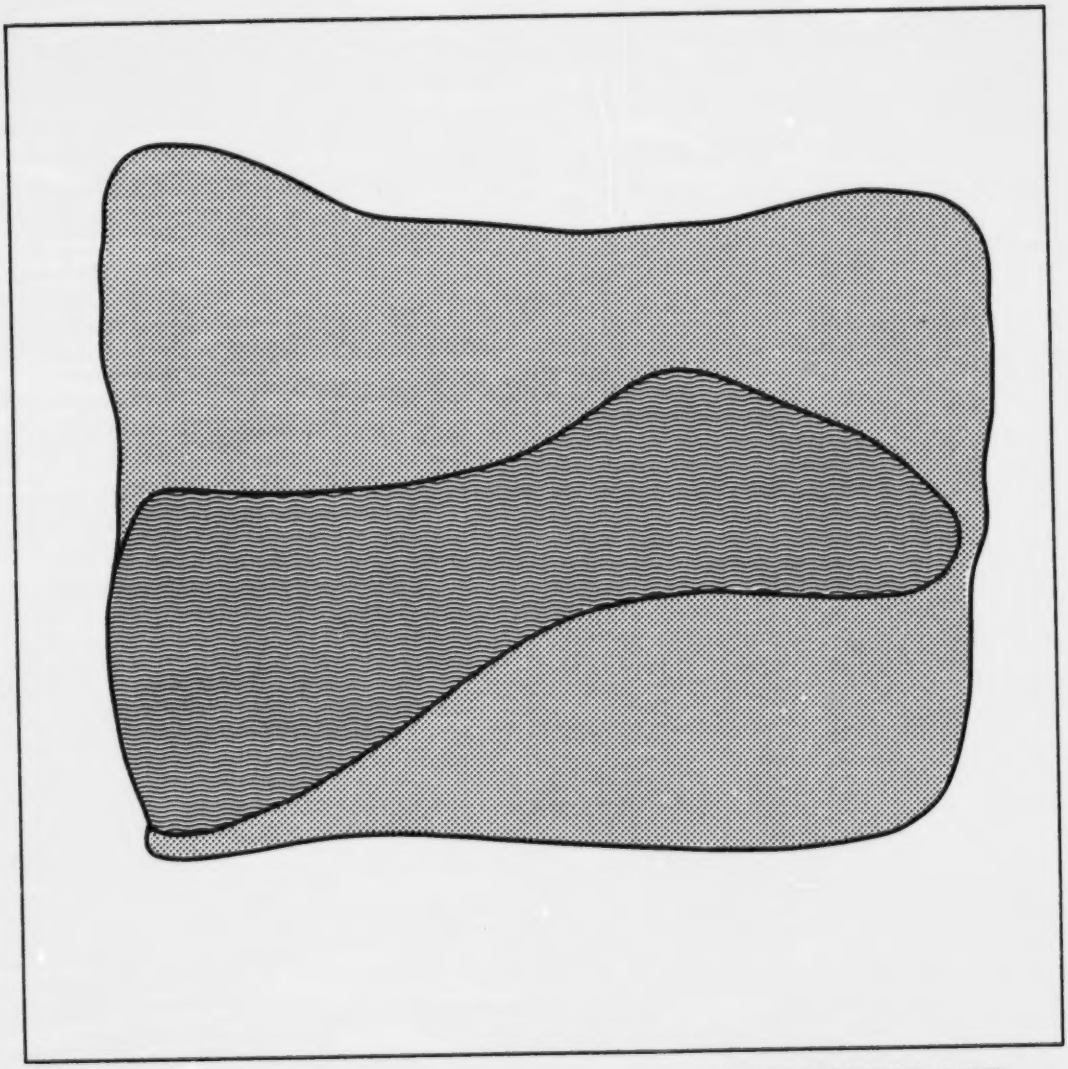
For the purpose of future reference, additional samples will be taken from the ESP bottom hoppers. These samples will be compared (in both organic content and PCB content) to those samples of the fly ash that have been collected at points b and b'. This procedure appears useful since it would allow the determination of the relative validity of the two sources of fly ash samples.

Bottom ash will be collected at the base of the boiler during the test burns. As previously mentioned, there is some concern as to the relationship between the grab samples that are available at a given time and the fly ash that is produced at the same time. The fly ash should be quickly swept out of the boiler, whereas, the processes by which the bottom ash eventually ends up in the bottom hopper are not nearly so clearly defined. This becomes a matter of concern when it is recognized that the bottom ash is possibly an important stream carrying out unburned PCBs. If the samples taken during a burn are actually historical samples resulting from processes that occurred earlier, this can lead to an over estimate of the combustion efficiency.

Gas flow Rate

The flow rate of the flue gases at both point b, b' d, and d' will be determined during sampling by the use of S pitot tubes that have been previously calibrated in the laboratory.

*Supplied by TVA operations personnel.



LEGEND:

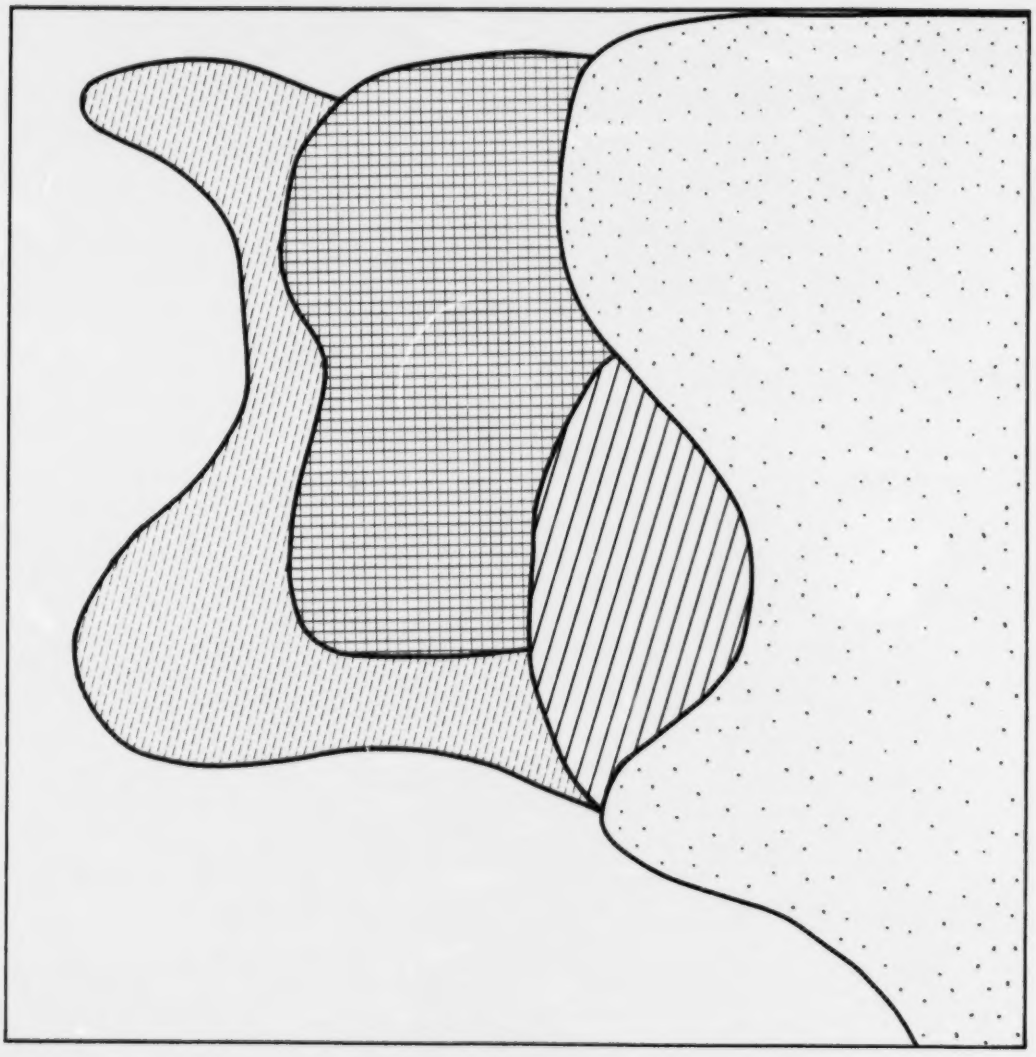
$0.97 \leq \sqrt{h} \leq 1.00$

$0.9 \leq \sqrt{h} \leq 0.97$

$\sqrt{h} < 0.9$

WHERE h IS THE MEASURED VELOCITY PRESSURE AND THE FLOW VELOCITY IS PROPORTIONAL TO $\sqrt{h}$.

FIGURE 6 VELOCITY PROFILE AT POINT b (FIGURE 1)



LEGEND:

- $330^\circ F \leq T \leq 340^\circ F$
- $340^\circ F \leq T \leq 350^\circ F$
- $350^\circ F \leq T \leq 360^\circ F$
- $360^\circ F \leq T \leq 370^\circ F$
- $T < 330^\circ F$

FIGURE 7 MEASURED TEMPERATURE DISTRIBUTION IN DUCT AT POINT b (FIGURE 1)

Concentration of Organics in the Flue Gases

As indicated schematically in Figure 1, the gas phase sampling will be carried out at the points marked b, b', d, and d' which are located on each side of the precipitators with a set on each of the two exit ducts from the boiler. Measurements at points b and b', which precede the cascade, are essentially for the purpose of determining the fly ash production rate (and to the extent possible, the relative proportion of PCBs and other combustion products associated with the fly ash particles). The sampling points d and d', which are located downstream of the cascade, are for monitoring the effluent PCBs and other possible combustion products.

The sampling at b and b' will be accomplished with the full Method Five using the RAC Staksampler^{R}. No attempt will be made to determine the particle size distribution; only the average concentration of particles and the average PCB concentration thereon will be of interest. Sampling at points d and d' (Figure 1) will be carried out for the determination of the residual levels of PCBs and other possible combustion produced products of the PCBs. The sampling train will be the Method Five train modified by the insertion of a Flurosil capsule between the third and fourth impingers. This procedure has been shown to more effectively collect organics than is the case of the normal Method Five sampling train.

The duration of the sampling scan and the method of treatment of the collected samples will be discussed in the section dealing with the analytical procedures to be used.

Combustion Gases

The PCB Regulations[1] state that there is a minimum concentration of excess oxygen in the flue gases below which complete combustion of the PCBs cannot be sustained. Similarly, the concentration of CO (relative to the concentration of CO_2) can be taken as a measure of the efficiency of combustion within the boiler; when the CO concentration rises beyond the limiting level, combustion efficiency has dropped to a point where complete combustion of the PCBs cannot be sustained. Since these quantities can readily be measured with existing on-stream analytical equipment (the same cannot be said for the very low allowable PCB concentrations), they are used as indicators that

conditions within the boiler are appropriate for the destruction of PCBs. Thus, it becomes essential that these quantities be measured continuously during the test burn. If any of these variables exceed the allowable levels, the PCB feed will be immediately shut down.

In addition to the continuous on-stream measurements of O_2, CO, and CO_2, periodic analyses of the major components of the flue gases will be made using the Orsat apparatus. This information is important in determining the molecular weight of the flue gases for sampling purposes.

COAL ANALYSIS

In addition to the analyses that are routinely carried out by TVA (as shown in Table 2), it will be of interest to determine the chlorine content of the coal. Therefore, samples of the pulverized material will be taken periodically during the feed of the PCB-contaminated oil for this purpose. It is anticipated that, by taking samples of the coal feed during the experiments, it will be possible to get a better and more representative determination of the ash content of the actual coal used during the experiment.

SECTION 5

PROGRAM IMPLEMENTATION

SAFETY MEASURES

Major factors that engender the seeming complexity of the feed system (Appendix A) are the need to prevent a PCB-contaminated oil spill and the subsequent exposure of the operating personnel. Essentially, the complexity of the system arises from the dual requirements of locating the transport vehicle outside the building and controlling, with great precision, the feed rate of the oil. A further complication is the need to contain any possible leakage from the system during feed operations. It should be noted, as shown in Appendix A, that the major units of the feed system are each self contained and provided with emergency shut down capabilities in case there is a leak or the pressure in the transfer line should drop. In addition to these self-contained safety features, the entire system, feed system and boiler, will be fitted so that if either the O_2 level in the effluent gases falls below the acceptable 3% or the CO concentration rises above 50 ppm, the PCB feed will immediately be shut off. Further, if the furnace operating conditions should markedly change from normal, there is a manual shutoff of the PCB feed.

The Versar team that will be on the site will be fully qualified to handle any cleanup operations that might be required.

PROCESS DATA SCHEDULE

The process variables will be determined on the schedule outlined in Table 8.

TABLE 8. PROCESS VARIABLE SCHEDULE

Process Variables	Measurement Schedule
By TVA	
Coal Feed Rate	Hourly
Primary Air Input	Hourly
Primary Air Temperature	Hourly
Boiler Internal Pressure	Hourly
Steam Generation Rate	Hourly
O_2 in Exhaust	15 Min Intervals
By Versar	
O_2 in Exhaust	Continuous Recorded 15 Min. Intervals
CO/CO_2 in Exhaust	Continuous Recorded 15 Min. Intervals
PCB Feed Rate	15 Minute Intervals
PCB Total Feed	At the End of an Experiment
Furnace Temperature	Hourly
Ambient Temperature	Hourly
Station Barometric Pressure	Daily
Gas Analysis of Flue Gases	Twice a Day (Orsat)

The sampling rates for the various effluent streams aside from the stack stream will be as follows:

ESP hoppers	50 gram sample taken from No. 1 and 2 on both a and b ducts every two hours, all samples collected in one run to be composited to yield two composite samples for analysis.
Bottom ash	Same as for ESP collected fly ash.
PCB-oil	Trickle sample collected during each b, b' run. Each treated as separate sample for analysis.

The sampling schedule for the gaseous streams will be as indicated on the proposed daily schedule as shown in Table 9.

TABLE 9. DAILY SCHEDULE OF ACTIVITIES

0800 - set up samplers at points b and d (Figure 1).
0830 - begin PCB feed at preselected rate.
0900 - begin sampling at b and d.
0930 - take ash sample bottom and at precipitator hoppers.
1030 - take ash sample bottom and at precipitator hoppers.
1100 - complete first sample at b, prepare for second sample at b.
1130 - begin second sample at b.
1130 - take bottom ash and precipitator hopper samples.
1230 - take bottom ash and precipitator hopper samples.
1330 - take bottom ash and precipitator hopper samples.
1330 - complete second sample at b.
1330 - complete sample at d.
1330 - 1430 - move samplers to b' and d' and set up.
1430 - begin first b' sample.
1430 - begin d' sample.
1430 - take bottom ash and precipitator hopper samples.
1530 - take bottom ash and precipitator hopper samples.
1630 - complete first b' sample.
1630 - take bottom ash and hopper samples.
1700 - begin second b' sample.
1730 - take bottom ash and hopper samples.
1830 - take bottom ash and hopper samples.
1900 - complete second b' sample.
1900 - complete d' sample.
1900 - secure PCB feed.
2000 - secure equipment.

TVA has asked that there be some assurance that the results of a given test be in hand before the next test commences, which results in a significant change in the time that the field crews will have to spend on the site. It was originally thought that the entire series of experiments could be completed, including before and after backgrounds, in a period of some six days with a

TABLE 10. FIELD SCHEDULE FOR PCB TESTS*

Preliminary	
Day 1	Begin procurement of components for feed system.
Day 14	Begin construction of feed system.
Day 44	Begin tests of assembled Module 1 and 3 of feed system.
Day 50	Transport completed Modules 1 and 3 to site.
Day 51	Begin assembly of Module 2 on site.
Day 55	Complete installation of feed system and check it out.
Field	
Day 0	Full field crew arrives; sampling equipment and monitoring equipment set up and checked.
Day 2	Background runs.
Day 3	First PCB feed run; stack samples sent to laboratory.
Day 5	Results of first run available; second run carried out; stack samples sent to laboratory.
Day 7	Results of second run available; third test carried out; stack samples sent to laboratory.
Day 8	Cleanup and second background run.
Day 9	Equipment secured and field crew returns to Springfield

*It is not clear at present just how long a delay will be occasioned by the need for analytical data on the emission levels prior to the beginning of the next experiment. If the delay is as is visualized in Table 10, then there will not need to be a large number of background runs. This latter matter also depends on the ambient levels of PCDFs and PCDDs found in the background runs. Evidently, this question can only be settled after the initial background and low feed rate experiments have been completed.

crew of seven people. The requirement that, at least, semi-quantitative data on the emissions be available introduces an unavoidable delay between the individual tests.[9] The delay is caused by the time required to transport samples to the Versar laboratories plus the time required for sample preparation and semi-quantitative analysis. During this interval, the field team will simply have to wait since the costs of sending them back and forth coupled with the time that that would require would greatly increase the costs of the program.

The estimated field schedule for field operations that results from the requirement that there be at least preliminary qualitative data on the completed experiment prior to the beginning of the next experiment follows. No attempt is made at this time to determine the actual starting date for the field study; only the duration is indicated by Table 10.

SECTION 6

ANALYTICAL PROCEDURES

INTRODUCTION

Hutzinger and his coworkers[4] have reviewed the procedures for the analyis of fly ash samples and have summarized the available results to date. As a result of this discussion, it seems reasonably clear that most, if not all, combustion sources produce measurable quantities of both the chlorinated dibenzofurans (PCDFs) and the chlorinated dibenzo-p-dioxins (PCDDs) as well as a variety of chlorinated benzenes. In the context of the proposed PcB incineration program at Widow's Creek, this information is extremely important since the possibility that these compounds will be present as background will tend to confuse the observed results when PCB-contaminated oil is being fed to the system. Clearly, obtaining a good background sample is very important.

The Hutzinger work[4] also indicates that the major vehicle for the removal of the PCDFs and the PCDDs from an incinerator is the fly ash collected within the precipitators and the fly ash carried out in the stack effluent. In point of fact, the data indicate that the concentrations of both classes of compounds increase with decreasing particle size and that the largest concentrations are in the stack fly ash. These concentrations have usually been in the range of several hundred parts per billion.

Because the largest proportion of the fly ash is collected in the ESPs (although the exact proportion of collected/emitted fines is unknown), proper sampling of this source is of great significance. Therefore it has been proposed that these samples be collected by direct application of EPA Method Five at the sampling points marked b and b' (Figure 1). Futher verification will be obtained by comparing samples from the ESP collection hoppers to samples taken from the gas stream.

ANALYTICAL RATIONALE

In view of the large number of samples expected from these experiments and the complex nature of the organic combustion products that can be expected, it is imperative that the analytical program be designed to quickly and accurately answer several very explicit questions. In particular, it is necessary to first determine the presence or absence (to the detection limit of the analytical procedure) of members of the classes of chlorinated biphenyls (PCBs) and the chlorinated dibenzofurans (there has, to date, been no observation indicating that PCDDs may be formed from PCBs). In those samples that indicate the presence of either or both of these classes on compounds, it will then be necessary to identify the specific compounds present and to determine the concentration of each species present. Thus, the analytical procedure to be adopted will consist of several steps leading up to a screening of the sample by perchlorination.[10] In spite of the intense controversy that surrounds this procedure, it is especially well adapted to the requirements of this program. After the sample has been carried through a series of cleanup steps to remove most of the organic components, part of the final extract will be treated with antimony pentachloride, according to the procedure described by Armour and co-workers and suitably modified to deal with PCDFs.[10] The resulting material will then be chromatographed to determine the presence (or absence) of octachlorodibenzofuran (OCDF) and/or decachlorobiphenyl (DCB). The absence of these compounds can then be taken as positive evidence that neither of the precursors, the PCBs or the PCDFs, is present in the sample, and no further analyses are required of that sample. On the other hand, the presence of either of the indicator species in the perchlorinated sample, will require that the remaining sample extract be subject to detailed analysis for the individual PCBs and PCDFs by more conventional methods.

In order to prevent misunderstanding, the perchlorination procedure is not proposed for the purpose of quantitative analyses of the derived samples. It will be used purely as a screening method to determine the presence or absence of either the PCBs or the PCDFs. The absence of either of the indicator species (the decachlorobiphenyl and the octachlorodibenzofuran) in a perchlorinated sample may be taken as <u>necessary and sufficient</u> for the finding that neither the PCBs nor the PCDFs are present in the sample. On the other hand, the presence of the indicator species in the perchlorinated sample is

necessary but not sufficient for the finding that the PCBs and/or the PCDFs are present in the sample. In this case, a detailed analysis of the sample must be carried out to confirm the presence of the precursor species. By using the perchlorination procedure in this manner, the heart of the controversy is avoided; no attempt will be made to quantitatively determine the PCB/PCDF concentration by perchlorination.

STACK SAMPLES

As has previously been discussed, it will be necessary to carry out an analysis of the samples taken from the stack (positions d and d' in Figure 1) before the next experiment begins. The samples that will be derived from this source will consist of two parts: (a) the contents of the first two impingers, the filter, the washings from the cyclone, and the washings from the probe and (b) the florisil capsule assembly. Sample (a) will then consist of particulates, a filter, and a complex water-organic solvent system. Initial preparation will involve filtering the suspension and than separating the organic solvent from the organic-water complex. The retained organic solvent will then be combined with the extractant from the solids and from the florisil capsule (the latter two will be treated as discussed in the next section). The entire extractant will then be concentrated, and a portion of the concentrate will be treated for perchlorination. The remainder of the concentrated sample will be retained for detailed analysis if that is required.

GENERAL ANALYTICAL PROCEDURE

A general schematic diagram of the analytical procedure is shown in Figure 8. The treatment of the fly ash and bottom ash samples has recently been shown[4] to require special measures in order to ensure complete recovery of PCDFs and PCDDs. Those measures are discussed below. Fly ash (50 g) is stirred with 1N HCl (200-400 ml). After separation by centrifugation, the residual ash is washed with deionized water through a Buchner funnel and dried at room temperature. The dried ash is then transferred to a soxhlet apparatus and extracted with toluene for 35 hours. The extractant, after concentration to 1-2 ml, is chromatographed on a series of two columns. The upper column contains 4 gms of silica loaded with 40% (wt) of H_2SO_4. The lower column contains layers of 2 gm silica gel loaded with NaOH (1 weight part of 1 N NaOH to 2 weight parts of silica gel), 2 gms $AgNO_3$ loaded silica gel (10%

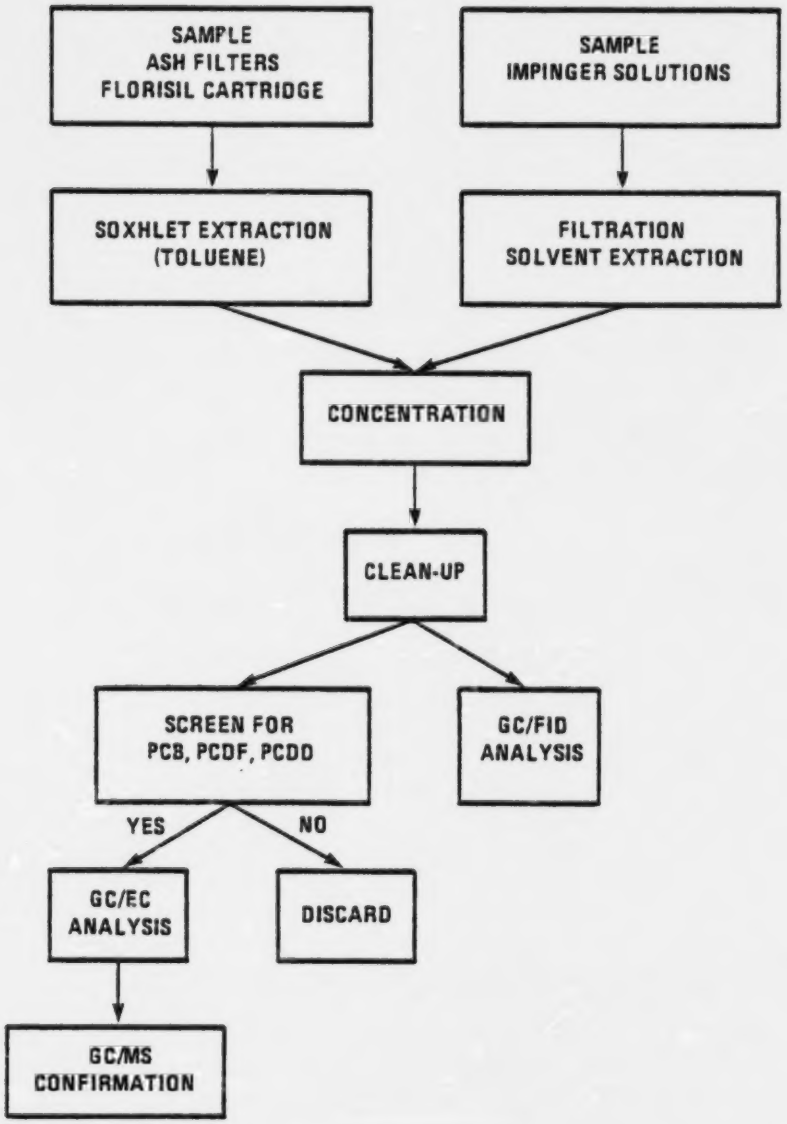


FIGURE 8 ANALYTICAL SCHEME

$AgNO_3$ by weight), and finally 1 gm silica gel. The columns are eluted with redistilled n-hexane after which the eluent is concentrated by evaporation. The PCDDs and the PCDFs are then separated from the chlorobenzenes on a column loaded with 1 gm basic aluminum oxide. That column is first eluted with 10 ml 2:98 methylene chloride:n-hexane to elute the chlorinated benzenes and then with 10 ml of a 50:50 mixture of methylene chloride:n-hexane. The florisil capsule, as well as the filter and solids from the sampling team, will receive the same treatment as the fly ash so as to obtain the highest possible recovery.

Flame Ionization Detection/Packed Column Separation

The extracts will be analyzed for total hydrocarbon content by FID techniques. A packed column with a liquid phase of OV-101 will be used for separation. Quantitation will be performed by comparison to an alkane mixture of C_7 to C_{14} hydrocarbons. The analytical conditions are as follows:

Hardware—

GC:	Hewlett-Packard 5730
Detector:	Hewlett-Packard flame ionization
Column:	10% OV-101 on 100/120 Supelcoport, 3 ft. x 2 mm glass

Conditions—

Temperature Program:	Initial Temp.	80°C
	Rate	8°C/min
	Final Temp.	250°C
Carrier Gas:	Nitrogen, 30 ml/min	
Injection Port Temperature:	250°C	
Detector Block Temp:	300°C	
Detector Gases:	H_2 at 30 ml/min	
	Air at 250 ml/min	

SAMPLE SCREENING BY PERCHLORINATION

A portion of the chromatographed sample extract (10-50 ml) is placed in a 2 ml flat bottomed reaction vessel and gently dried with a stream of nitrogen. A small volume (50 ml) of a mixture of equal parts of Analabs

Reagent A_1 and A_2* is added, and the teflon-lined cap is loosely placed on the reaction tube. The tube is then placed in an aluminum block suitably drilled to retain the reaction tube and fitted with a thermometer well. The reaction is allowed to proceed for 20 to 30 minutes at a temperature of 70°C, after which the cap is tightened and the tube allowed to cool to room temperature. Approximately 200 microliters of 20% HCl (previously purified by washing with hexane) is added to the reaction vessel and shaken and then several 1 ml portions of hexane are extracted. The final hexane extract is treated with a small amount of sodium bicarbonate to neutralize. This final extract can then be injected into a suitable GC/EC for detection of the perchlorinated products.

It has been found that the use of the Analabs reagents is somewhat more gentle than the use of antimony pentachloride since the latter has been shown to convert some of the PCDFs to chlorinated benzenes.

SAMPLES THAT SHOW THE PRESENCE OF PCBs OR PCDFs ON PERCHLORINATION[12]

Those samples that give a positive indication on perchlorination will then be subjected to more complete analysis using a glass capillary column coupled with electron capture detection. The system will be operated in the grab-style splitless mode to vent off any residual hydrocarbon interferences.

Hardware--

GC:	Varian 3700 with glass capillary system (splitless mode)
Detector:	Varian linear Ni^{63} electron capture
Column:	Se-54, 30 meters

Conditions--

Temperature Program:	Initial Temp.	200°C
	Initial Hold	2 min.
	Rate	4°C/min
	Final Temp.	270°C
Carrier Gas:	5% methane/argon	
Linear Velocity:	40 cm/sec	
Injection Port Temperature:	150°C	
Detector Temperature:	300°C	
Purge Time:	45 sec.	

*Reagents A_1- and A_2-perchlorination agents are available from Analabs, North Haven, CT, under their catalog number RCS-079.

DETERMINATION OF THE PCB FEED RELATED OXYGENATED COMPOUND PRODUCTION

As has previously been stated, one should expect to find detectable levels of such oxygenated compounds as the PCDFs and the PCDDs in the fly ash as well as the stack particulate matter even in the absence of PCB feed; i.e., as background. It would be highly desirable if one could simply subtract the levels of these compounds found in a background run from those observed during the PCB feed experiments, but the concentration variations that have been observed[4] seem to preclude this simple procedure. On the other hand, since the thermal conditions within the boiler can be expected to remain approximately the same during the series of tests, one should expect to find the the PCB-derived PCDFs increase in concentration at a rate following the PCB feed rate.

A further consequence of the "normal" presence of PCDFs and PCDDs in the fly ash and the emitted particulate matter and of the expected concentration variations is the requirement that each test be preceded by at least one complete background scan, especially of the stack emissions.

An additional possibility exists for the determination of the rate of production of the PCDFs from the PCB feed. The background samples should show a relatively constant relationship between the concentrations of PCDF and PCDD that are formed from precursors within the fuel. This relationship will probably be noticeably disturbed if significant proportions of the PCB feed are converted into PCDFs.

SECTION 7

PRELIMINARY ENVIRONMENTAL ASSESSMENT

The primary population center in the vicinity of the Widow's Creek power plant is Bridgeport, Alabama, which is located approximately 5 km (3 mi) to the northeast of the plant. Since Bridgeport is downwind of the Widow's Creek plant, it is important to determine the possible exposure to which Bridgeport residents might be exposed as a result of the proposed tests. We proceeded according to the TVA Dispersion Model,[13] which seems appropriate since the site is a TVA operation. The procedure is to first determine the effective stack height for several atmospheric stability conditions (as determined by the magnitude of the lapse rate) and then, for each of these atmospheric conditions, to determine the point of maximum atmospheric concentration at ground level. The next step is to estimate that maximum concentration for the several feed rates and for the several conditions of the assumed destruction ratio for the system.

The stack height is taken to be 304 m (1000 ft) with an inside diameter at the top of 6 m (19.7 ft). The estimated combustion gas flow (assuming that all six units are in operation during the test) is taken to be 6.5×10^4 m^3/min at a temperature of 180°C (370°F), and the estimated gas flow velocity at these conditions is 38.3 m/sec at stack top.

ATMOSPHERIC STABILITY CONDITIONS

The standard description of atmospheric stability is given in terms of the lapse rate as shown in Table 11.

TABLE 11. ATMOSPHERIC CLASS STABILITY DEFINITIONS

Stability Class	Type	Lapse Rate (°K/100 m)
0	Unstable	less than -0.22
1	Neutral	-0.22 through +0.15
2	Neutral	+0.15 through +0.85
3	Stable	Greater than +0.85

TVA PLUME RISE CALCULATIONS

As a result of extensive empirical study TVA[13] has developed several equations that take into account the fact that the plume appears to arise from a height greater than that of the actual stack. This phenomenon is a result of the elevated temperature of the stack gases as compared to the ambient atmosphere, the momentum of the emergent gases, and the density difference between the stack gases and the ambient air. Several situations have been treated for stability conditions under classes 1, 2, and 3. The results derived from each of these classes are tabulated for conditions at Widow's Creek in Table 12.

TABLE 12. ESTIMATED PLUME HEIGHT INCREASE FOR VARIOUS STABILITY CLASSES

Stability Class	Effective Height Increase* (m)
1	628
2	519
3	269

*estimates based on a downwind distance of 5000 m (the distance to Bridgeport, Alabama).

MAXIMUM GROUND LEVEL CONCENTRATION (MGLC)

As an extension of the TVA studies of the plume from an incinerator and the expected ground level concentration (GLC) at various downwind distances from the stack, equations have been reported[14] that allow the estimate of the point at which the GLC is a maximum and that allow an estimate of the

one hour concentrations to be expected at various points on the trajectory of the plume. Here again, the estimates are dependent on the atmospheric conditions that prevail, as was the case for the plume height estimates. Table 13 summarizes the results of the calculations for the MGLC in the downwind direction.

TABLE 13. ESTIMATED POINT OF MGLC FROM TVA METHOD[13]

Stability Class	Description	X_{max} (m)
3 to 2	Inversion breakup	32000
3	Trapping	3000
1 or 2	Coning	2.8×10^{6}

*Wind speed has been taken as constant at 4.5 m/sec (10 m/hr)

We may now carry the estimates further to examine the probable surface concentrations at a point 5,000 m northeast of the stack site (the approximate location of Bridgeport, Alabama). The results of these calculations for several feed rates and for several values of the destruction ratio are summarized in Tables 14 through 16.

TABLE 14. ESTIMATED MGLC FOR INVERSION BREAKUP CONDITIONS*

Feed Rate (l/hr)	One Hour PCB Concentration at 5 km			
	Zero Destruction		99.9% Destruction	
	($\mu g/m^3$)	(ppb)+	($\mu g/m^3$)	(ppb)+
76	8.8×10^{-4}	7.5×10^{-4}	8.8×10^{-7}	7.5×10^{-10}
228	2.6×10^{-3}	2.21×10^{-3}	2.6×10^{-6}	2.21×10^{-9}
456	5.3×10^{-3}	4.5×10^{-3}	5.3×10^{-6}	4.5×10^{-9}

*Assuming that feed material contains 83 ppm PCBs.

+Air temperature taken to be 30°C.

It is to be noted that these levels are orders of magnitude below NIOSH standards.

TABLE 15. ESTIMATED MGLC FOR TRAPPING CONDITIONS*

Feed Rate (l/hr)	One Hour PCB Concentration at 5 km			
	Zero Destruction		99.9% Destruction	
	($\mu g/m^3$)	(ppb)+	($\mu g/m^3$)	(ppb)+
76	8.4×10^{-5}	7.14×10^{-3}	8.4×10^{-8}	7.14×10^{-8}
228	2.5×10^{-4}	2.12×10^{-4}	2.5×10^{-7}	2.12×10^{-7}
456	5.1×10^{-4}	4.33×10^{-4}	5.1×10^{-7}	4.33×10^{-7}

*Assuming that feed material contains 83 ppm PCBs.

+Air temperature taken to be 30°C.

TABLE 16. ESTIMATED MGLC FOR CONING DISPERSION CONDITIONS*

Feed Rate (l/hr)	One Hour PCB Concentration at 5 km			
	Zero Destruction		99.9% Destruction	
	($\mu g/m^3$)	(ppb)+	($\mu g/m^3$)	(ppb)+
76	7.66×10^{-5}	6.5×10^{-5}	7.7×10^{-8}	6.5×10^{-8}
228	2.3×10^{-4}	1.95×10^{-4}	2.3×10^{-7}	1.95×10^{-7}
456	4.6×10^{-4}	3.9×10^{-4}	4.6×10^{-7}	3.9×10^{-7}

*Assuming that feed material contains 83 ppm PCBs.

+Air temperature taken to be 30°C.

EVALUATION OF MGLC CALCULATIONS

The results that are tabulated in Tables 14 through 16 must be viewed with caution since there are a number of assumptions contained therein in addition to those assumptions on which the TVA procedure is based. Most of the approximations that are involved are of such a nature as to render the estimates high rather than low. Specifically, it has been assumed that the only effluent stream that is responsible for the removal of unburned PCBs is the stack gas stream. There is strong reason to believe that a considerable portion of the unburned PCBs will be associated with the bottom and fly ash, thus reducing the estimate of the emission rate from the stack. Further, the stated estimates are based on a computed emission rate of combustion gases (which is probably high since it was assumed that all the available combustibles were consumed), on an assumed stack temperature, and on an assumed constant wind velocity directed toward Bridgeport.

A detailed examination of the TVA estimate for the MGLC shows that the GLV depends inversely on the velocity of emission of the stack gases at the top of the stack. In view of this fact, the situation in which only Number One boiler is in operation would simply result in an approximately six-fold increase in the estimates of the MGLC. Actually, this is an overestimate since the plume height also depends on the emission velocity and thereby would be decreased, thus reducing both the position of the maximum touch-down concentration as well as the MGLC somewhat below the above estimate.

To interpret the significance of the estimated GLC that can be expected at a point some 5 km northeast of the stack, we note that the average human adult requires a respiratory volume of 30 m^3 in 24 hours. Under the worst conditions, inversion breakup with zero destruction, with only one boiler in operation and with the maximum feed rate, the estimated exposure level is of the order of 3×10^{-2} $\mu g/m^3$. The duration of the tests is not expected to exceed 10 hours during which an exposed adult human would inhale some 0.3 µg of PCBs. The overall program is expected to result in some 24-30 hours of PCB feed during which the exposed individual might be expected to receive a total exposure of 1 to 2 µg under the worst case conditions.

To assess the significance of this worst case exposure, we note that the Threshold Limit Value (TLV) for occupational exposure to PCBs has been set at a level of 37 ppb. The TLV is computed on the basis of exposure for 8 hours per day for five days a week for a normal working life. If we assume a normal respiratory volume for such a worker, the TLV value corresponds to the cumulative exposure to a total of some 435 µg per eight hour working day without either acute or chronic ill effects. A comparison of the TLV with the anticipated worst case exposure indicates that, for the duration of the proposed experiments, even under worst case conditions, there is no discernible danger to the population of Bridgeport, Alabama.

SECTION 8

STATISTICAL ANALYSIS OF RESULTS

An important aspect of this Task Assignment is the requirement that the validity of the experimental values of the PCB destruction efficiency be established by detailed statistical analysis of the data. Examination of the physical layout at Widow's Creek has shown that there is apparently no reliable method of determining the rate of production of fly ash and bottom ash. Further, the means of access to these two effluent streams is such that there is no easy way to determine whether or not samples taken are representative of the actual effluent streams. Under these circumstances (where the uncertainties contained in the measured data are undetermined) statistical analysis seems inappropriate.

It would appear that, under such circumstances, the resulting destruction ratio measurements will be difficult to evaluate. In the specific event that the concentration of PCBs (and possibly intermediate products) found in the fly ash and in the bottom ash is essentially at or below detection limits (on the order of 1 ppb) then we may estimate, as shown below, the destruction ratio difference that derives from the unseen PCBs in these two effluent streams using a feed rate of coal given as 5.08×10^4 kg/hr (56 tons/hr) with 15% ash and a PCB detection level of 1 ppb of ash.

To estimate the effect of the detection limit it is noted that the PCB emission rate in the ash could be as high as

$$Q_o \sim 5.08 \times 10^4 \times 10^3 \times 0.15 \times 1 \times 10^{-9} = 7.63 \times 10^{-3} \text{ gm/hr.}$$

without having been detected. If the feed were at the rate of 100 gal/hr of oil with density of 8 lb/gal and PCB concentration of 450 ppm, then the feed rate (Q_{in}) will be:

$$Q_{in} = 100 \times 8 \times 454 \times 4.5 \times 10^{-4} = 163 \text{ gm/hr.}$$

Thus:

$$DE = \frac{Q_{in} - Q_o}{Q_{in}} \times 100 = 99.995\%.$$

Hence, the absence of PCBs in the ash would allow the statement that

$$DE \geq 99.995\%.$$

As has been previously discussed, there is every reason to believe that the physical arrangements at Widow's Creek are essentially the same as at many other similar coal-fired utility boilers. Thus, the results that will be obtained in the proposed experiments should be applicable to any such plant. Also, the same considerations as to the precision of the DE measurements will apply to any similar plant.

SECTION 9

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APPENDIX A

DETAILED DESCRIPTION OF PCB/OIL FEED SYSTEM FOR USE AT WIDOW'S CREEK

INTRODUCTION

The PCB-feed system has been designed to provide several special features such as complete containment in the event of a leak in the system; complete control of the feed rate coupled with continuous measurement of that feed rate; provisions for the continuous extraction of a sample from the low pressure side of the PCB feed system; and the capability to shut off the feed system in the even of an emergency such as the excursion of the O_2 content beyond the allowable range, the decrease in the boiler temperature below the acceptable level and so forth. The details of each portion of the system are described in the material that follows.

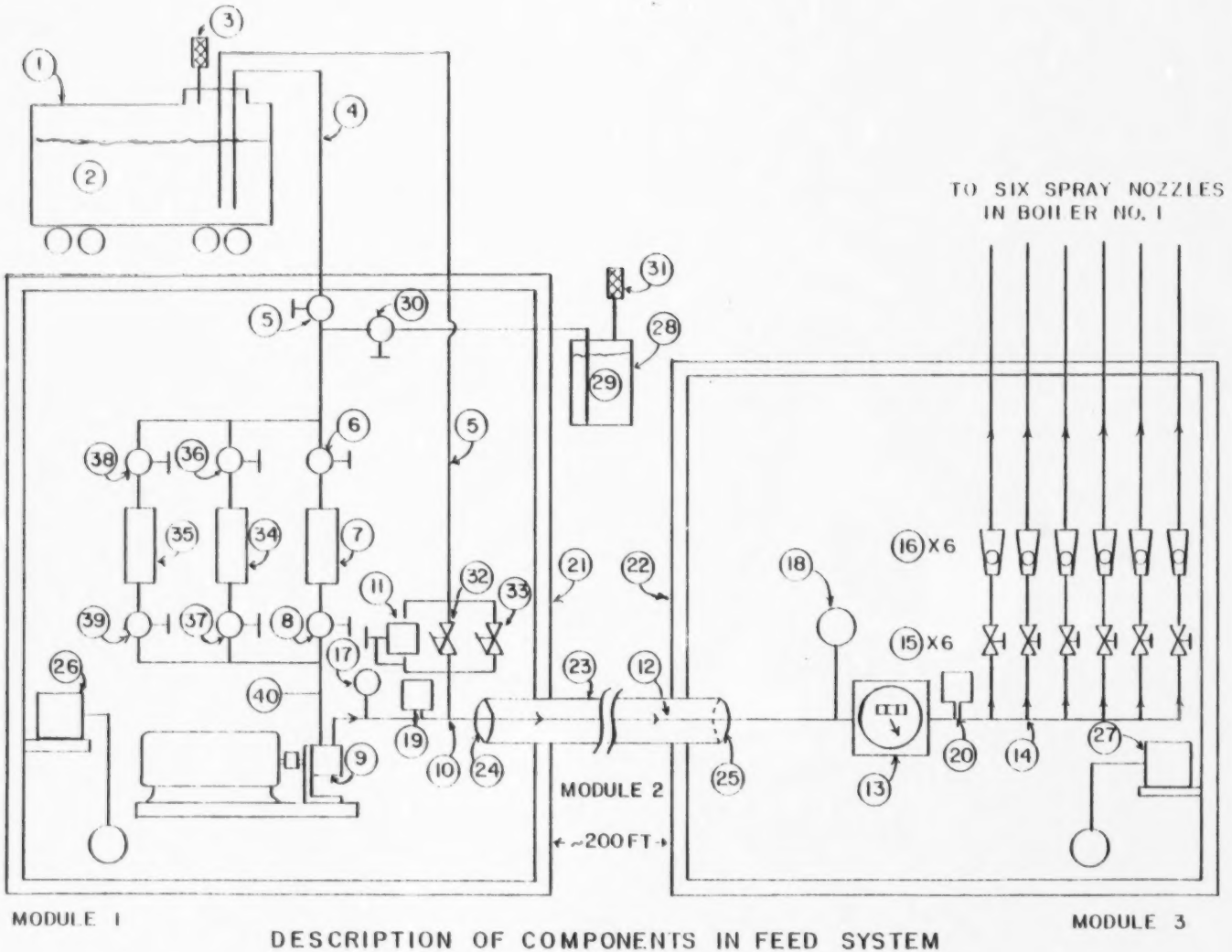
DETAILED DESCRIPTION OF FEED SYSTEM

The detailed hydraulic description of the feed system is shown in Figure A-1. Table A-1 contains the component description of the feed system, keyed to the numbered components in Figure A-1.

Methodology of Feed System

Referring to Figure A-1, the feed solution (2) will be drawn from storage vessel (1) via suction line (4), ball valves (5) and (6), filter (7), and ball valve (8) to the inlet of pump (9) where it will be exhausted to the high pressure side of the pump. The liquid removed from the storage vessel will be replaced with air which is directed to pass through the activated charcoal filter (3); the filter will serve as the barrier between the air space above the PCB contaminated mineral oil and the air outside the storage vessel.

The liquid forced out the exhaust side of the pump will pass to tee connector (10) where part of it will be recycled back to storage vessel (1) through back pressure regulator (11) and return line (5). The other portion of the feed solution will pass through a 200-foot run of hydraulic line (12) which will be



DESCRIPTION OF COMPONENTS IN FEED SYSTEM

FIGURE A-1

Table A-1

Component Description of Feed System

(1) Storage Vessel for PCB Contaminated Mineral Oil
(2) PCB Contaminated Mineral Oil (feed solution)
(3) Activated Charcoal Filter
(4) Suction Line
(5) Ball Valve
(6) Same as (5)
(7) Basket Strainer (filter)
(8) Same as (5)
(9) Liquid Pump
(10) Tee Connection
(11) Back Pressure Regulator
(12) 200 Foot Transfer Line
(13) Flow Accumulator
(14) Manifold Splitter
(15) Flow Regulating Valves
(16) Flow Indicator
(17) Pressure Gauge
(18) Same as (17)
(19) Hi-Lo Pressure Switch
(20) Same as (19)
(21) Sealed Enclosure
(22) Same as (21)
(23) Conduit
(24) Open End of Conduit
(25) Same as (24)
(26) Liquid Level Float Switch
(27) Same as (26)
(28) Solvent Vessel
(29) Solvent
(30) Same as (5)
(31) Activated Charcoal Filter
(32) Pressure Relief Valve

Table A-1 (Con't)

Component Description of Feed System

(33) Same as (32)

(34) Same as (7)

(35) Same as (7)

(36) Same as (5)

(37) Same as (5)

(38) Same as (5)

(39) Same as (5)

(40) PCB-Oil Sampler - See Figure A-7 for details

contained in module 2. Further downstream, the feed solution will enter module 3 where it will pass through a flow accumulator (13), the outlet of which will be split into a maximum of six streams at a manifold (14). The number of these streams in operation will depend on the feed rate requirements of the incineration test. If the feed rate requirement is 20 gallons per hour, then only one of these lines will be in operation. If the feed rate requirements are 60 or 120 gallons per hour, then three or six lines, respectively, will be in operation.

Each one of the six streams will pass through a flow regulator (15) and a flow meter (16) before entering the inlet to the spray nozzle(s) attached to Boiler Number 1.

The fluid pressure will be monitored via gauges (17) and (18) in modules 1 and 2, respectively. In addition, hi-lo limit pressure switches, (19) and (20), will be positioned in modules 1 and 2 to shut off the feed pump in case there is an unscheduled drop or increase in pressure on the upstream side of the pump. Either directional change in pressure will indicate malfunctioning in the feed system which will require immediate shut-down of the pump.

The components of modules 1 and 3 will be encased in a sealed enclosure (21) and (22), to contain the feed solution in the event a malfunction should occur in the operation of the feed system. The long run of hydraulic feed line (12) in module 2 will be enclosed in a sealed conduit (23) whose terminal ends (24) and (25) will be internally connected to the enclosures of modules 1 and 3. Should any leaks develop along this long hydraulic line, the leaking feed solution will flow to one of these enclosures. Furthermore, located near the bottom of both enclosures (21) and (22) of modules 1 and 3 will be a liquid level float switch (26) and (27) which will be electrically connected to the pump to shut it off in the event of an unscheduled leak in modules 1, 2, and 3.

A solvent vessel (28) will be located near module 1 and will contain an adequate PCB solvent (29), such as trichlorobenzene, to clean up the feed system at the termination of the incineration test. To operate the feed system in the purge mode will require closing ball valve (5) and opening ball valve (30) to fluid flow. The solvent will then be vented to the atmosphere via activated charcoal filter (31).

In order to obtain representative samples of the PCB-contaminated oil, an automatic sampler (operation shown in Figure A-7) is connected to the low pressure recycle line at point 40 in Figure A-1. This device will extract a 5 ml sample every 5 minutes. At the end of each two-hour period, the collected sample will be removed.

Two inline relief valves, (32) and (33), will be situated parallel to the back pressure regulator; those valves will be adjusted to a higher pressure setting than the back pressure regulator (11) so as to quickly relieve the pressure in event that the back pressure regulator (11) should malfunction.

The components of the feed system have been carefully gauged so as not to create an excessive pressure drop during the operation of the feed system. For example, the component of module 2, the 200 foot transport section, will consist of copper tubing with an inside diameter of 0.527 inches. At the highest feed rate of 120 gallons per hour, the pressure drop across the long run of copper tubing will be approximately 20 psi. The pressure required to operate the spray nozzles will be on the order of 180 psi. Therefore, the high pressure side of the pump will be carefully controlled by the back pressure regulator (11) near 200 psi.

It should be noted that the pressure of the feed solution is controlled by a back pressure regulator which regulates the upstream pressure. Thus the feed solution pressure is controlled on the high pressure side of the pump rather than the low side. This is contrary to conventional downstream pressure control and is of particular importance because it permits the regulation of pressure without having to artificially increase the stream pressure above that of the controlled pressure as is the case with a conventional downstream pressure regulator.

Another important feature of the feed system will be the filtration subsystem. Liquid filters (7), (34), and (35) will be situated in the low pressure side of the pump in a parallel fashion, allowing for independent or multiple operation of the liquid filters (7), (34), and (35). This will be accomplished through the proper adjustments of ball valves (6), (8), (36), (38), and (39). The actual filters will be (sealed) basket strainers, each strainer having an effective surface area of 17 square inches. The pore size of the strainers will be approximately 318 micrometers.

A parts list of the components of the feed system has been assembled and will be presented in the following subsection of this document. The parts lists (and cost of each part) will be presented in conjunction with a carefully prepared hydraulic diagram of each of the major subsystems. The component number in each of the parts lists will be keyed to the component number shown in each of the diagrams. A summarized parts list for the entire feed system will be found at the conclusion of this subsection.

Port connections to storage vessel and solvent vessel—

The parts list of the port connections is shown in Table A-2. An illustration of the assembled port connection to the storage vessel is shown in Figure A-2. An engineering drawing of the connecting flange and gasket is shown in Figure A-3. The quantity in the parts list was doubled for the solvent vessel port connection.

Module 1--Module 1 contains the pump, the filtration assembly, and the pressure control hydraulics. The parts list for module 1 is presented in Table A-3. The component diagram of module 1 (keyed to the parts list) is shown in Figure A-4.

Module 2--The long transport section between module 1 (near the storage vessel) and module 3 (near boiler unit number 1) will comprise module 2. The parts list for this module is shown in Table A-4. The component diagram is displayed in Figure A-5.

Module 3--Module 3 contains the flow control and monitor portion of the feed system. Its parts list and component description are shown in Table A-5 and Figure A-6, respectively.

Cost Summary--

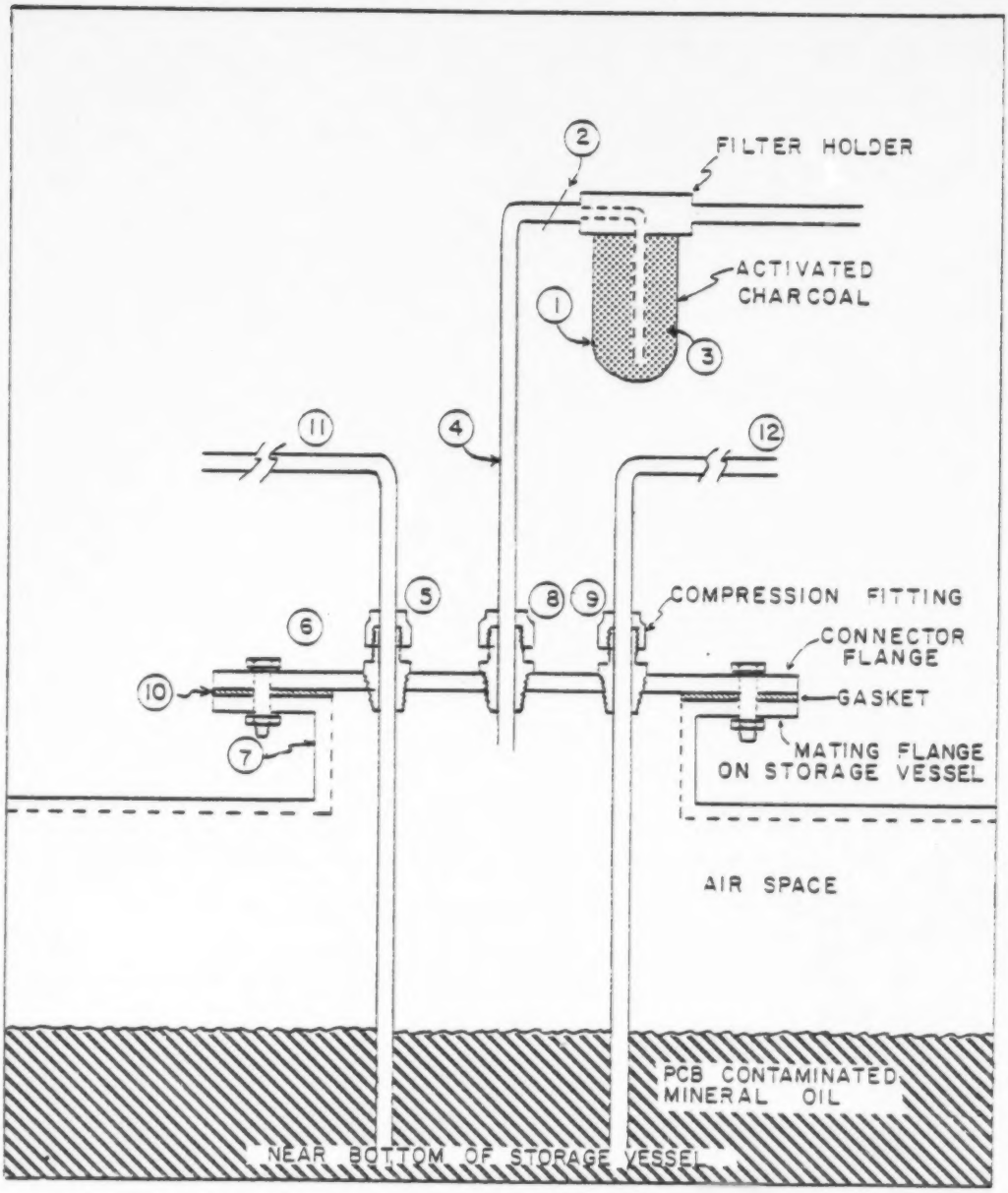
Presented below is the summarized estimate of cost for the component parts of the feed system. The total estimate of cost for purchase or manufacture of the components is estimated to be on the order of $9,000.00

SUMMARY OF COST OF COMPONENTS

1.	Port Connection to Storage Vessel	$ 329.00
2.	Port Connection to Solvent Vessel	329.00
3.	Module 1	2,540.97
4.	Module 2	379.00
5.	Module 3	5,026.03
6.	Miscellaneous	500.00
	Total	$9,104.00

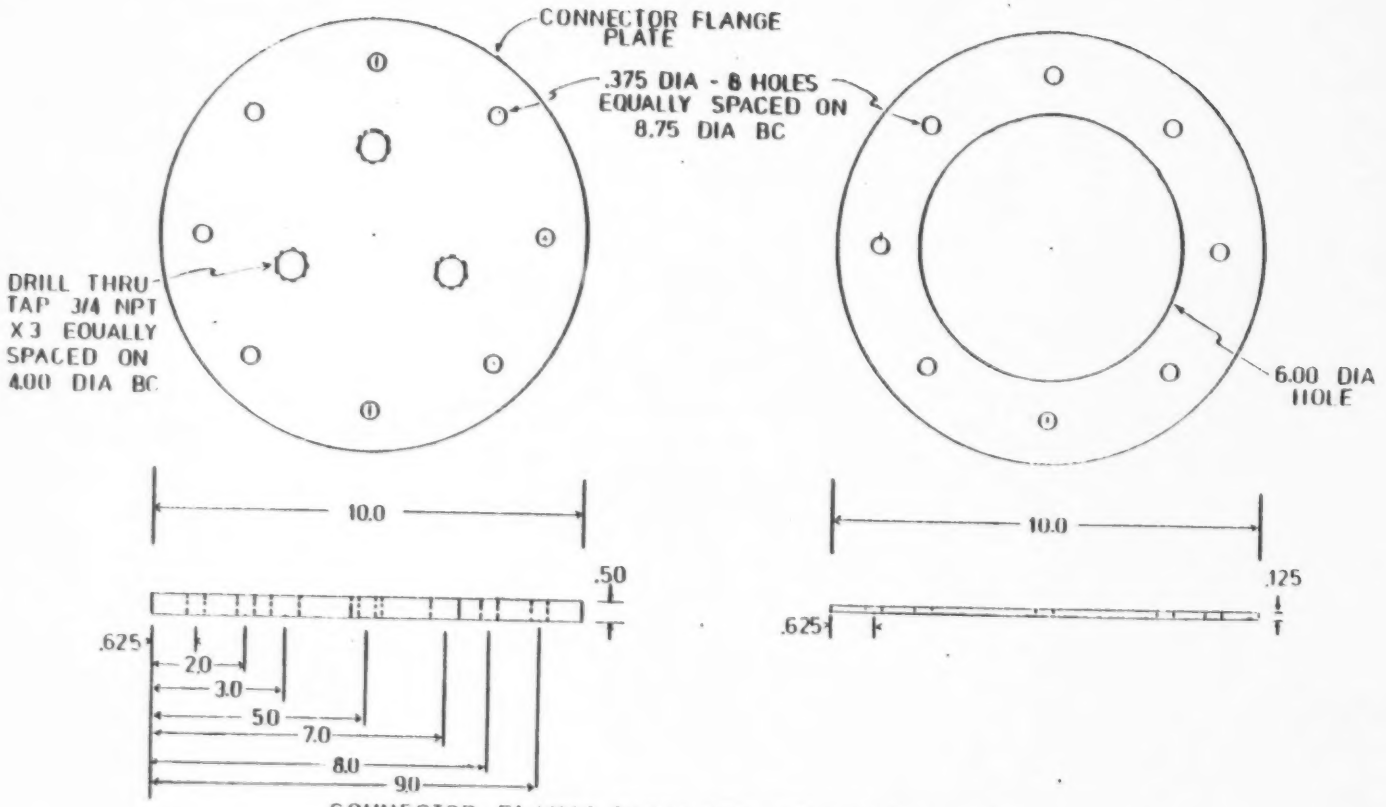
Table A-2. PARTS DESCRIPTION FOR ASSEMBLED PORT CONNECTION TO STORAGE AND SOLVENT VESSELS

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(1)	2	Filter Holders	Wilkerson	X03-02-000	$ 60.00	$120.00
(2)	2	5/8" Swagelok to 2/8" MPT	Swagelok	B1010-1-6	3.00	6.00
(3)	2	Activated Charcoal, 2 lbs.	Scientific Products	4394	32.00	64.00
(4)	2	5/8" OD x .035" Wall x 2' long Carbon Steel Tubing	Tubesales	1010	4.00	8.00
(5)	2	5/8" Swagelok to 3/4" MPT	Swagelok	1010-1-12	4.00	8.00
(6)	2	Connector Flange	Subcontract to Mach. Shop	---	100.00	200.00
(7)	2	Mating Flange	Subcontract to Mach. Shop	---	100.00	200.00
(8)	2	5/8" Swagelok to 3/4" MPT	Swagelok	1010-1-12	4.00	8.00
(9)	2	5/8" Swagelok to 3/4" MPT	Swagelok	1010-1-12	4.00	8.00
(10)	2	Viton Gasket (see Figure 5)	Subcontracted to Mach. Shop	---	10.00	20.00
(11)	2	High Density Polyethylene Tubing 25 feet, 5/8" OD x .500" ID	Reed Plastics	---	4.00	8.00
(12)	2	High Density Polyethylene Tubing, 25 feet, 5/8" OD x .500" ID	Reed Plastics		4.00	8.00



ASSEMBLED PORT CONNECTION
TO STORAGE VESSEL

Figure A-2



CONNECTOR FLANGE PLATE AND VITON GASKET TO BE MOUNTED TO MATING FLANGE ON STORAGE VESSEL

Figure A-3

Table A-3. PARTS DESCRIPTION FOR MODULE 1

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(1)	1	5/8" Union Tee Connector	Swagelok	B1010-3	$ 9.00	$ 9.00
(2a.)	1	3/8" FPT to 5/8" Swagelok	Swagelok	B1010-7-6	4.00	4.00
b.)	1	3/8" MPT to 1/4" MPT Reducing Nipple	Cajon	B6HRN-4	2.00	2.00
(3)	1	Hi-Lo Pressure Switch with Adjustable Range between 25 to 275 PSIG	SOR Inc.	7723-XXX	275.50	275.50
(4)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(5a.)	1	3/8" FPT to 5/8" Swagelok	Swagelok	B1010-7-6	4.00	4.00
b.)	1	3/8" MPT to 1/4" FPT Reducer Bushing	Cajon	B6RB4	2.00	2.00
(6)	1	300 PSI Oil Gauge 1/4" Bottom Connection	Grangers	4X5 14	3.80	3.80
(7)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(8)	1	5/8" Swagelok to 1/2" MPT	Swagelok	B1010-1-8	3.00	3.00
(9)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(10)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(11)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(12)	3	Adjustable In Line Relief Valves; 1/2" MPT Inlet, 1/2" FPT Discharge Pert-Teflon Seats	Grangers	1P786	12.69	38.07
(13)	3	1/2" FPT to 5/8" Swagelok	Swagelok	1010-7-8	4.00	12.00
(14)	3	1/2" MPT to 5/8" Swagelok	Swagelok	1010-1-8	3.00	9.00
(15)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(16)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(17)	1	5/8" Union Elbow	Swagelok	B1010-9	6.00	6.00

(Continued)

Table A-3 (Con't)

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(18)	1	5/8" Bulkhead Union	Swagelok	B1010-61	7.50	7.50
(19)	1	Cast Iron Rotary Gear Pump; 7/16" Dia. x 1 5/16" Shaft Length; 1800 RPM	Granger	1P908	99.57	99.57
(20a.)	1	Explosion-Proof Motor 1725 RPM, 115/230, 5/8" Dia. x 1 7/8" long Shaft	Granger	6K041	163.00	163.00
b.)	1	Coupling Body	Granger	4x182	2.00	2.00
c.)	1	Spider	Granger	2x814	1.00	1.00
(21)	1	Mounting Frame and Hardware	Fischer Hardware	---	10.00	10.00
(22)	1	5/8" Swagelok to 1/2" MPT	Swagelok	B1010-1-8	3.00	3.00
(23)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(24)	3	5/8" Swagelok to 1/2" MPT	Swagelok	B1010-1-8	3.00	9.00
(25)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(26)	1	5/8" Union Elbow	Swagelok	B1010-9	6.00	6.00
(27)	6	Ball Valves, Angle Pattern 1/2 FPT Connection	Whitey	B-45F8	53.00	318.00
(28)	6	1/2" MPT Hex Nipples	Cajon	B-8-HN	12.00	72.00
(29)	3	Basket Type Strainers 80 Mesh Screens; 16 in^2 Open Screen	John F. Krauss Co.	#D28	80.00	240.00
(30)	1	5/8" Union Elbow	Swagelok	B1010-9	6.00	6.00
(31)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(32)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(33)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00

(Continued)

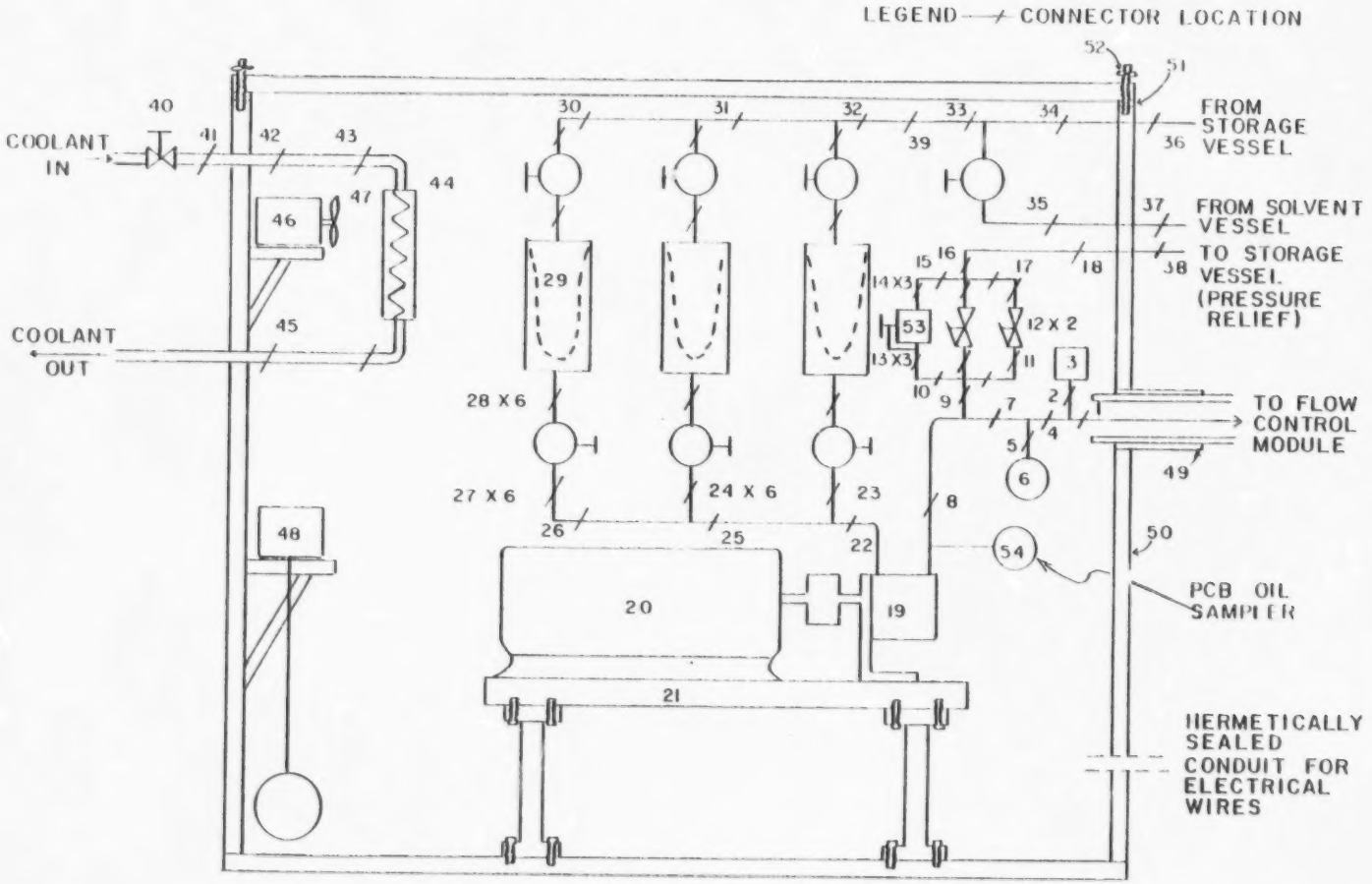
Table A-3 (Con't)

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(34)	1	5/8" Bulkhead Union	Swagelok	B1010-61	$ 7.50	$ 7.50
(35)	1	5/8" Bulkhead Union	Swagelok	B1010-61	7.50	7.50
(36)	1	High Density Polyethylene Tubing, 25 feet, 5/8" OD x .500" ID	Reed Plastics	---	~ 4.00	~ 4.00
(37)	1	High Density Polyethylene Tubing, 25 feet, 5/8" OD x .500" ID	Reed Plastics	---	~ 4.00	~ 4.00
(38)	1	High Density Polyethylene Tubing, 25 feet, 5/8" OD x .500" ID	Reed Plastics	---	~ 4.00	~ 4.00
(39)	1	Copper Tubing, 10 feet x 5/8" OD x .049" Wall; Rated 1002 PSI	Potomac Vave & Fitting	---	~10.00	~10.00
(40)	1	Water Valve, 1/2" FPT	Granger	6X404	5.10	5.10
(41)	1	5/8" Swagelok to 1/2" MPT	Swagelok	B1010-1-8	3.00	3.00
(42)	1	5/8" Bulkhead Union	Swagelok	B1010-61	7.50	7.50
(43)	1	Copper Tubing, 10 feet x 5/8" OD x .049" Wall; Rated 1002 PSI	Potomac Vave & Fitting	---	~10.00	~10.00
(44)	1	Heat Exhanger; Kool Klutch	Edsall Auto Supply	141010	~20.00	~20.00
(45)	1	5/8" Bulkhead Union	Swagelok	B1010-61	7.50	7.50
(46)	1	Internally Fan-Cooled Motor; General Purpose; Continuous Duty; 1/4" Shaft Diam.; 1/70 HP	Granger	3M560	~10.00	~10.00
(47)	1	10" Hub-Type Fan Blades	Granger	2C538	1.00	1.00
(48)	1	Float Switch	Square D	9036 DRIR	74.88	74.88

(Continued)

Table A-3 (Con't)

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(49)	5	Cast Acrylic Tube,	Reed Plastics	---	$ 20.55	$ 20.55
(50)	2	Sheets Plexiglass, GM Masked Both Sides 4'x8'xl/2"	Reed Plastics	---	168.00	336.00
(51)	1	1/2" x 10' Rubber Gasket	Fischer Hardware	---	~ 4.00	~ 4.00
(52)	8	1/4" Bolts and Wing Nuts	Fischer Hardware	---	~ .50	~ 4.00
(53)	1	Liquid Service Back Pressure Regulator	Fisher Controls	---	587.00	587.00

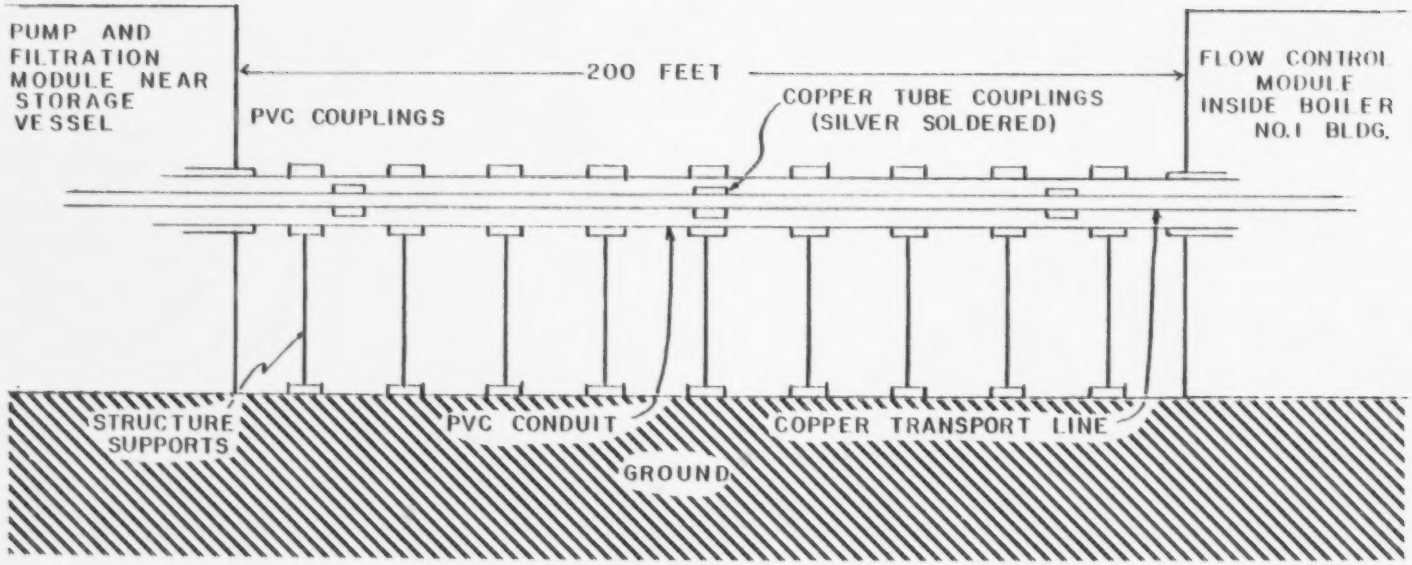


MODULE I

FIGURE A-1

Table A-4. PARTS DESCRIPTION OF PCB CONTAMINATED MINERAL OIL TRANSFER SECTION (MODULE 2) BETWEEN MODULE 1 AND MODULE 3

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(1)	4	Copper Tubing, 5/8" OD x 0.049" Wall, 50 foot rolls	Potomac Valve & Fitting	---	$ 50.00	$200.00
(2)	3	Copper Tubing Couplings	Fischer Hardware	---		2.00
(3)	1	1 1/2" PVC Pipe; 10 pcs. x 20 foot long Schedule 40 (1.592" ID)	Reed Plastics	---	150.00	150.00
(4)	9	PVC Couplings	Reed Plastics	---		6.00
(5)	20	8" Cinder Blocks as Structure Supports	Fischer Hardware	---		6.00
(6)	1	Silver Solder and Butane	Fischer Hardware		15.00	15.00



PCB CONTAMINATED MINERAL OIL TRANSFER SECTION
BETWEEN STORAGE VESSEL AND BOILER BUILDING

Figure A-5

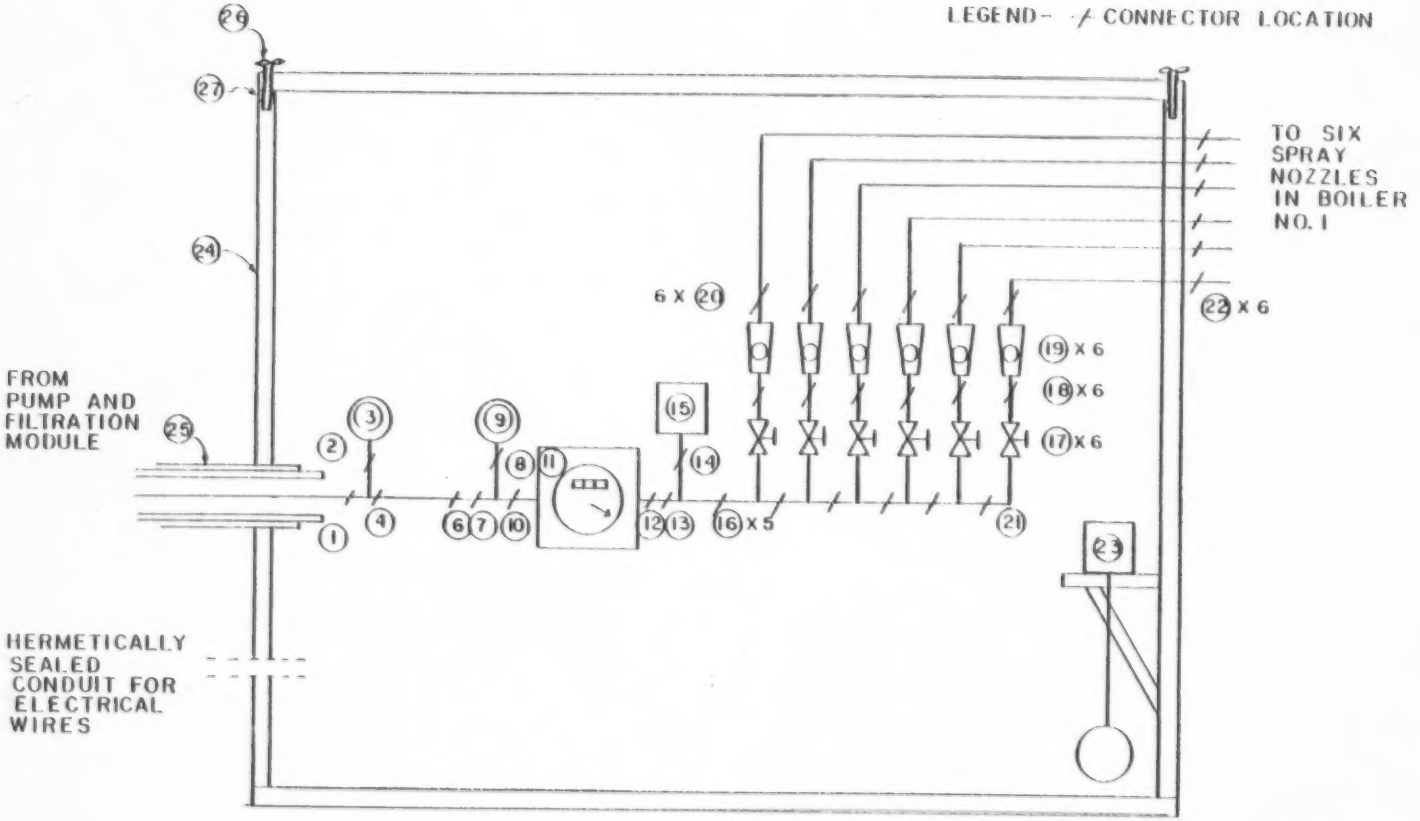
Table A-5. PARTS DESCRIPTION FOR MODULE 3

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(1)	1	5/8" Union Tee Connector	Swagelok	B1010-3	$ 9.00	$ 9.00
(2a.)	1	3/8" FPT to 5/8" Swagelok	Swagelok	B1010-7-6	4.00	4.00
b.)	1	3/8" MPT to 1/4" FPT Reducer Bushing	Cajon	B6RB4	2.00	2.00
(3)	1	300 PSI Oil Gauge - 1/4" Bottom Connection	Grangers	4X514	3.80	3.80
(4)	1	1/2" MPT to 5/8" Swagelok	Swagelok	B1010-1-8	3.00	3.00
(5)	1	1/2" MPT to 5/8" Tube Male Connector	Swagelok	B1010-1-8	3.00	3.00
(6)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(7a.)	1	3/8" FPT to 5/8" Swagelok	Swagelok	B1010-7-6	4.00	4.00
b.)	1	3/8" MPT to 1/4" FPT Reducer Bushing	Cajon	B6RB4	2.00	2.00
(8)	1	300 PSI Oil Gauge 1/4" Bottom Connection	Grangers	4X514	3.80	3.80
(9)	1	1/2" MPT to 5/8" Swagelok	Swagelok	B1010-1-8	3.00	3.00
(10a.)	1	Positive Displacement Totalizer Meter	Brooks	9401	2,332.00	2,332.00
b.)	1	Differential Industive Converter	Brooks	4020B	854.00	854.00
(11)	1	1/2" MPT to 5/8" Swagelok	Swagelok	B1010-1-8	3.00	3.00
(12)	1	5/8" Union Tee Connector	Swagelok	B1010-3	9.00	9.00
(13a.)	1	3/8" FPT to 5/8" Swagelok	Swagelok	B1010-7-6	4.00	4.00
b.)	1	3/8" MPT to 1/4" MPT Reducing Nipple	Cajon	B-6-HRN-4	2.00	2.00
(14)	1	Hi-Lo Pressure Switch with Range Adjustment between 25 to 275 PSIG	Swagelok	B1010-3	9.00	9.00

(Continued)

Table A-5 (CONTINUED)

Item No.	Qty	Description	Company	Part No.	Price	Total Cost
(15)	5	5/8" Swagelok Union Tee Connector	Swagelok	B1010-3	$ 9.00	$ 9.00
(16)	6	Regulating Valve, .156 Orifice C_V = .43, Angle Pattern	Nupro	B-6JA	9.00	54.00
(17)	6	3/8" Swagelok to 1/2" MPT	Swagelok	B-600-1-8	3.00	18.00
(18)	6	Hi-Pressure through Flow Indicator	Brooks	Model 3604	184.00	1,104.00
(19)	6	3/8" Swagelok to 1/2" MPT	Swagelok	B-600-1-8	3.00	18.00
(20)	6	5/8" Union Elbow	Swagelok	B1010-9	6.00	36.00
(21)	6	3/8" Bulkhead Unions	Swagelok	B-600-61	4.00	24.00
(22)	1	Float Switch	Square Dee	9036 DRIR	74.88	74.88
(23)	2	Sheets Plexiglass GM Masked Both Sides 4'x8'x1/2"	Reed Plastics	---	168.00	336.00
(24a.)	1	Cast Acrylic Tube, OD = 2.250" 1/8" Wall - 5 foot section	Reed Plastics	---	20.55	20.55
b.)	1	Methylene Chloride, 1 gal. Solvent Grade	Fisher Chemical	D-37	~15.00	~15.00
(25)	8	1/4" Bolts and Wing Nuts	Fischer Hardware	---	.50	4.00
(26)	1	1/2" x 10' Rubber Gasket	Fischer Hardware	---	3.00	3.00
(27)		Misc. Mounting Hardware	Fischer Hardware			~20.00
(28)	100'	3/8" Copper Tubing	Potomac Valve & Fitting	---		~30.00



MODULE 3

Figure A-6

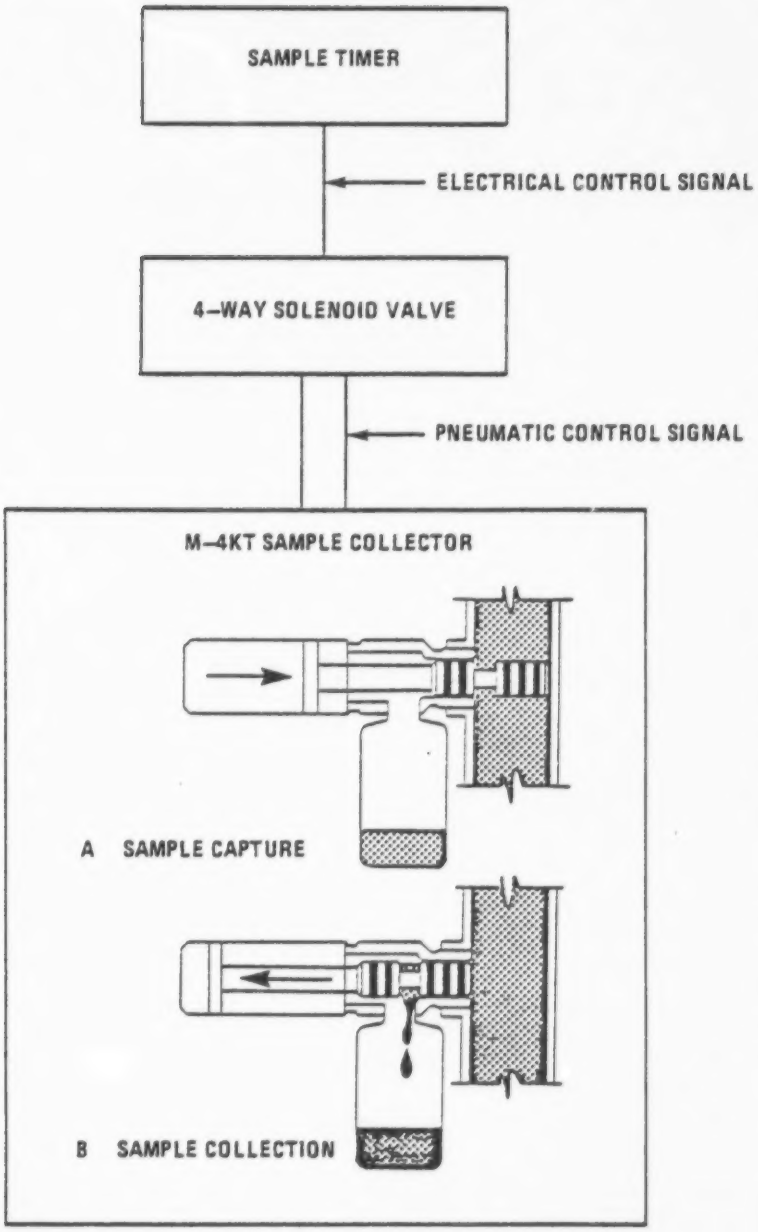


FIGURE A-7 PCB–OIL AUTOMATIC SAMPLING SYSTEM